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Oak Ridge National Laboratory

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THE COVER: *High-contrast treatment of a transmission electron micrograph showing Ni_3Ti precipitation in an experimental 3.0% titanium-modified Hastelloy N. The Ni_3Ti imparts a very high degree of strength to the alloy. Magnification is 120,000×.*

Oak Ridge National Laboratory Annual Report 1970-71

Operated by Union Carbide Corporation for the U.S. Atomic Energy Commission

FOREWORD

During 1970—71 peaceful nuclear energy came of age. Almost 100,000 megawatts of nuclear electricity are now installed or are on schedule to be installed in the United States. In the wake of this huge commitment to nuclear energy has come unprecedented public concern over the balance between the benefits and the risks of nuclear energy. None who are connected with the nuclear energy enterprise have been untouched by this enlarging public debate.

Oak Ridge National Laboratory during this past year has contributed much toward clarifying the underlying issues. A sampling of what we have found is recorded in this Annual Report. As for the risks of nuclear energy, we report work on safety of both light water reactors and of fast breeders, on waste disposal, and on technological assessment and the environment. We report also some of our work related to the benefits of nuclear energy: on development of fission and fusion breeders, and on applications of isotopes to medicine, for example. Unfortunately, space does not permit us to include an account of our studies of the applications of nuclear energy to desalting, agriculture, and other industry.

In this period of intense worry over the environment, there is hardly an annual report, whether it be of a corporation, a

government institution, or a laboratory, that does not speak to the contribution that institution has made to improving the environment. We hope the reader of our report will not be disappointed in this respect. During the past year, ORNL's involvement with the environment has continued to grow steadily. Much of this work at ORNL is now sponsored by the NSF as well as other agencies, but it is clear that what we learn in our non-AEC-sponsored work on the environment strengthens our capacity to contribute intelligently to resolving the problems of the environment posed by nuclear energy.

The report, as is our custom, includes vignettes of basic research in both the physical and biological sciences. I leave to the reader the pleasure of browsing through these items. He or she will find once again the enormously wide range of interest that is to be found in the research at ORNL.

Though this has been a year beset by financial adversity, I believe our scientific and technical accomplishments remain remarkably high. Of this we at ORNL — the supporting as well as the technical staff, all of whom persevered despite our difficulties to bring about the achievements recorded in this 1970—71 Annual Report — can be immensely proud.

Alvin M. Weinberg

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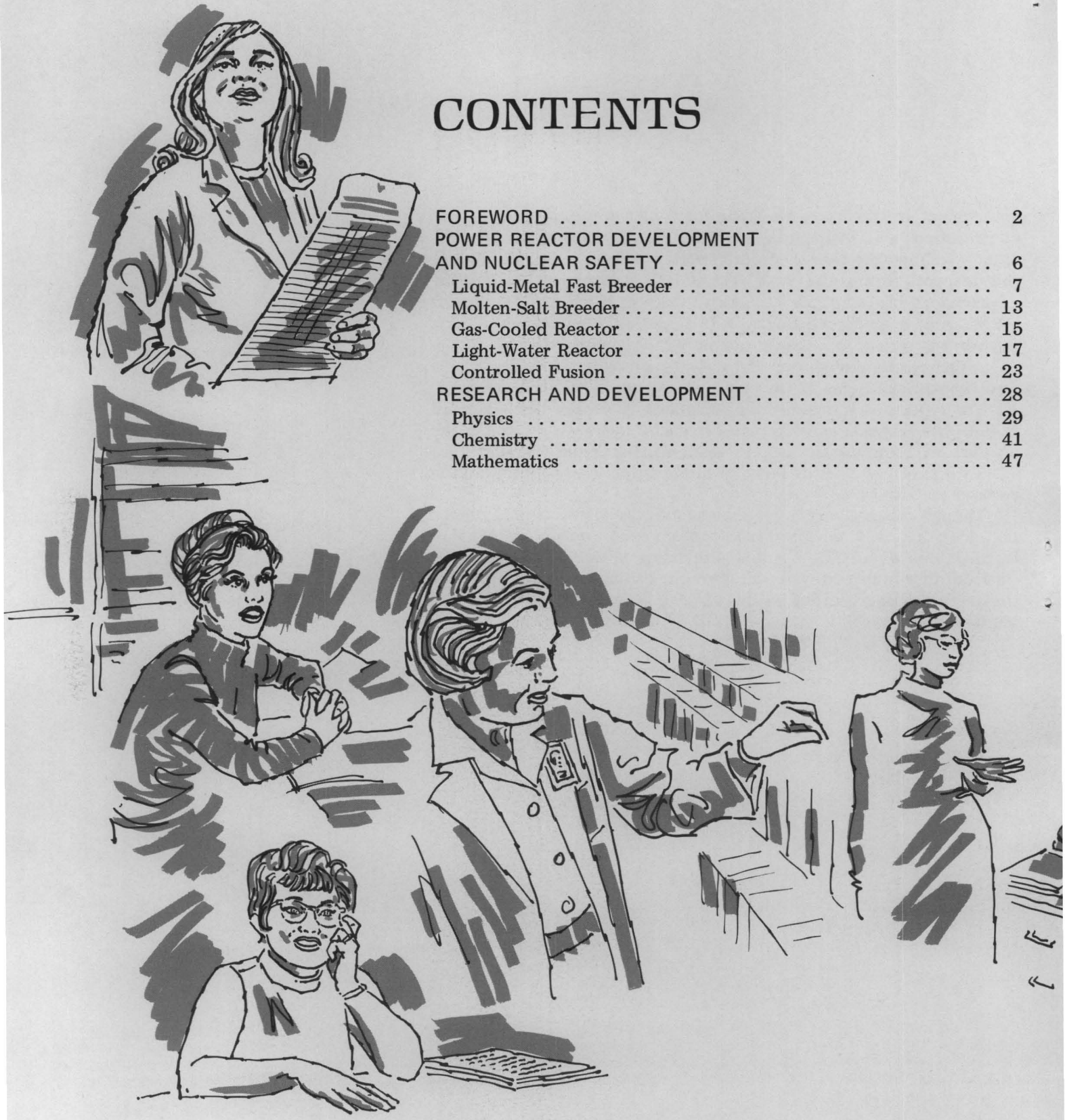

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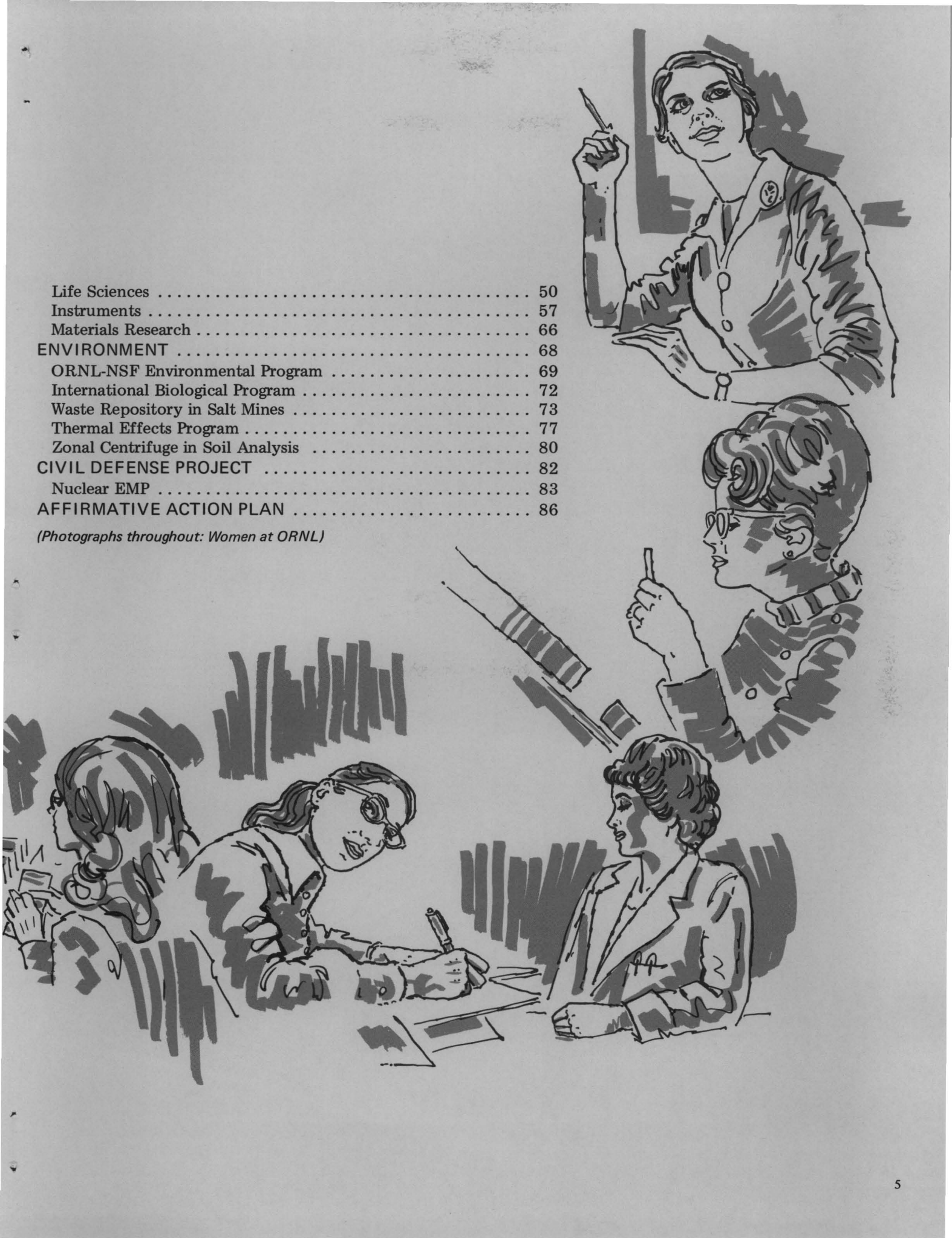
(Photographs throughout: Women at ORNL)

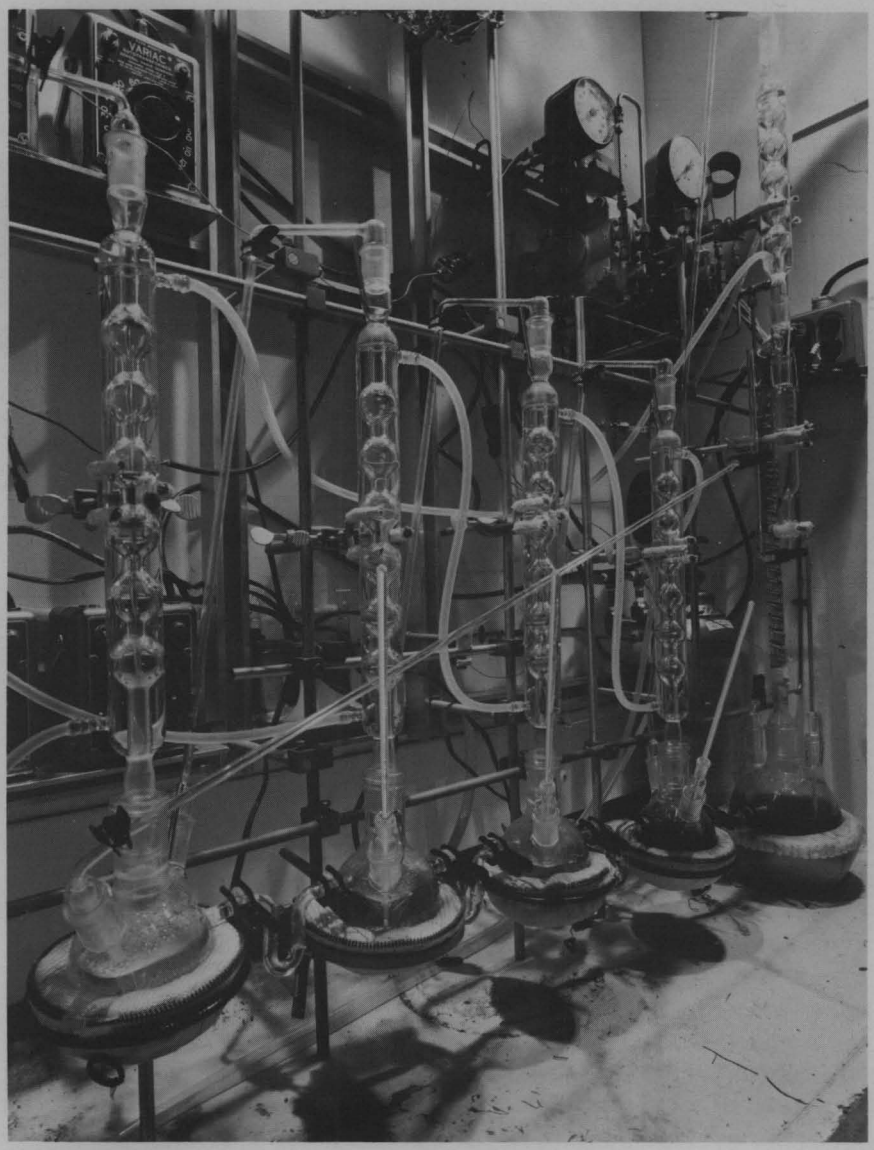


POWER REACTOR DEVELOPMENT AND NUCLEAR SAFETY

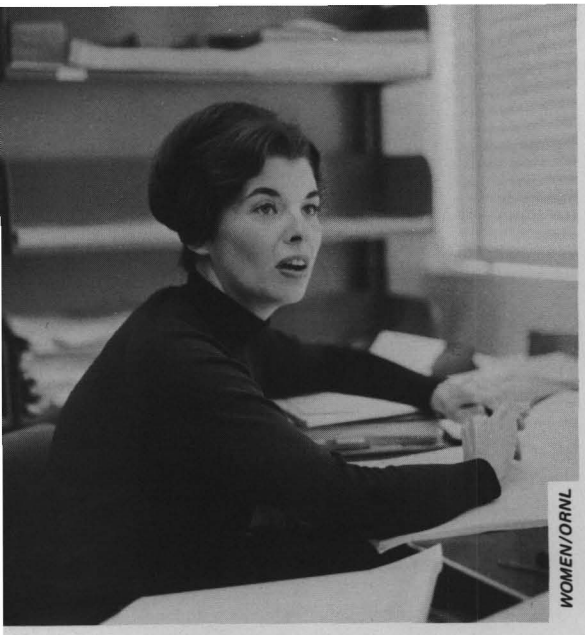
Liquid-Metal Fast Breeder

Fuel Recycle Studies

A process called Iodex has been developed at ORNL for removing the radioactive fission product iodine from the gas that is discharged during the reprocessing of spent fuel from the liquid metal fast breeder reactor.



Iodex — concentrated nitric acid process for removal of the fission product iodine from air. Air is bubbled through the four scrubbers in series, countercurrent to the flow of nitric acid from the distillation stage (extreme right), where the iodine is collected as a solution of iodic acid.



Pat Postma, mathematician

The breeder produces plutonium from uranium faster than it can burn plutonium, and the recovery of this additional fuel in usable form requires highly sophisticated chemical processes and techniques not found in conventional plants. The principal difference between the breeder fuels of the future and the fuels now being discharged from reactors is that the breeder fuels will contain more plutonium and more fission products such as iodine, xenon, krypton, and tritium.

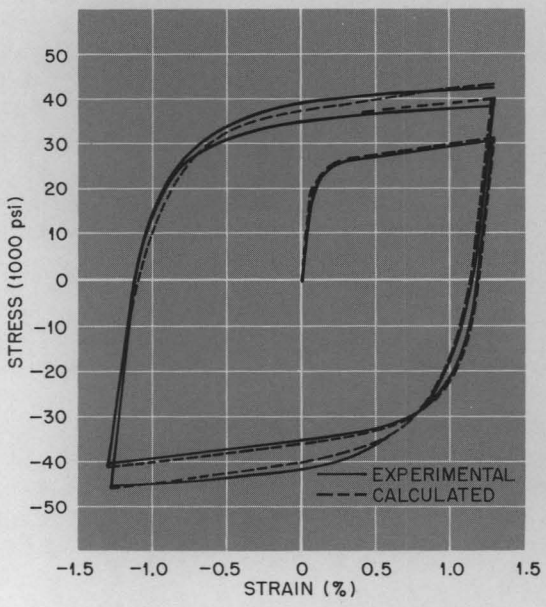
The fuel elements can be disassembled remotely by slitting their outside covering with a plasma torch and releasing the individual fuel rods, which can then be sheared in bundles of 50 to expose the interiors for processing. These pieces are heated in oxygen to release tritium, which is recovered as water. After leaching in nitric acid to dissolve the plutonium and uranium, the fuel rod hulls are compacted for economical waste disposal.

The gas that is discharged during the acid leach contains the fission products iodine and krypton. The Iodex process removes the iodine with concentrated nitric acid, which then can be separated from the iodine by evaporation and reused. The iodine precipitates as a solid, in which form it can be easily stored. The krypton is then removed from the off-gas with a fluorinated hydrocarbon scrub. These process innovations, developed at Oak Ridge, should enable chemical fuel reprocessing facilities to attain the "near-zero" release.

In addition, control of the iodine will permit processing after only 30 days' decay time, an economic advantage for fast breeder fuels, because the value of their high plutonium content greatly increases the penalty on out-of-reactor inventory time.

Structure Mechanics at High Temperatures

Experimental results on stress of stainless steel type 304 show remarkable agreement with predictive equations.



The pressure vessel and other structural components of liquid-metal-cooled fast breeder reactors (LMFBR's) will be operated at temperatures (up to 1200°F) considerably higher than those of comparable structural parts in conventional, water-cooled nuclear plants (600°F). This fact, coupled with the long design life requirements (30 to 40 years), partly invalidates many of the analysis techniques, design criteria, and safety codes and standards currently in use for water reactors. For example, at temperatures above 800°F, structural materials tend to creep under load; progressive distortion takes place as temperature levels oscillate (termed "thermal ratcheting"); large strains tend to concentrate in critical regions such as at welds; and fatigue damage becomes a complex, nonlinear phenomenon involving temperature, time, and nonlinear stress-strain relations. All of these effects are grouped together under the general heading of inelastic materials behavior.

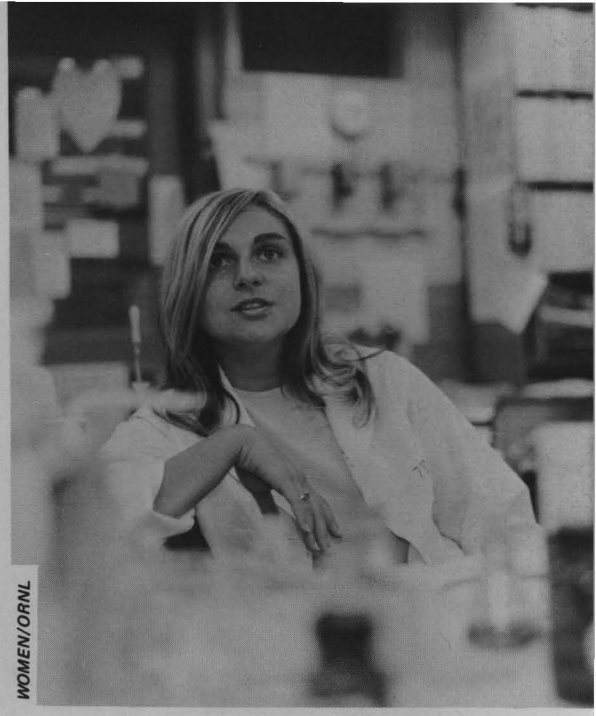
The main purpose of the ORNL program on structural design methods and criteria for LMFBR's is to investigate inelastic materials behavior at elevated temperatures and to develop proven structural analysis methods for use in design. This requires a coordinated effort between the metallurgist, the experimental stress analyst, and the theoretical mechanics expert to develop the mathematical analogs (constitutive equations) that describe the behavior of the material under general thermal and mechanical loading conditions. These

equations will then be used to predict the behavior of actual structural members instrumented and tested in the laboratory.

In order to facilitate the analytical predictions, large-scale computer programs are also being developed which incorporate the most current mathematical statements of materials behavior. As better constitutive equations are developed, these will be incorporated into the computer programs and tested against the experimental findings. The basic key to good predictions of the structural behavior is a set of verified constitutive formulations for the inelastic behavior of the particular material.

Toward this goal, constitutive equations were developed in 1970 to represent elastic-plastic behavior, in which the stress-strain relations are time independent, nonlinear, and irreversible, for type 304 stainless steel at room temperature. This mathematical model will be the basis for extensions to high-temperature behavior. The present development was based on observations from uniaxial tests in which specimens were subjected to different cyclic loading histories. A nonlinear kinematic hardening law was developed that describes the fundamental behavioral features including material hardening under repeated cycling and the change in yield strength as a function of loading history.

The physical model of the mathematical analog can be described as follows: The states of stress that define the transition from purely elastic behavior (in which the stress-strain relations are linear and reversible) to elastic-plastic behavior form a closed hypersurface, called the yield surface, in nine-dimensional stress space. In this hyperspace one dimensional direction is assigned to each of the stress components in the stress tensor. Thus, for a uniaxial test specimen which is alternately pulled or pushed, the stress space reduces to the stress axis of a conventional stress-strain diagram, and the yield surface reduces to the two points defining the yield stress in tension or compression. The material behaves elastically between the two yield points (elastic stress range) and plastically, in which nonlinear effects predominate, outside this range. In the case of 304 stainless, the yield surface translates in stress space as a function of past loading history but does not change in size. Multiaxial stress-strain relations based on this model have been successfully used to predict uniaxial cyclic behavior for type 304 stainless steel at room temperature, and verified with experimental results.



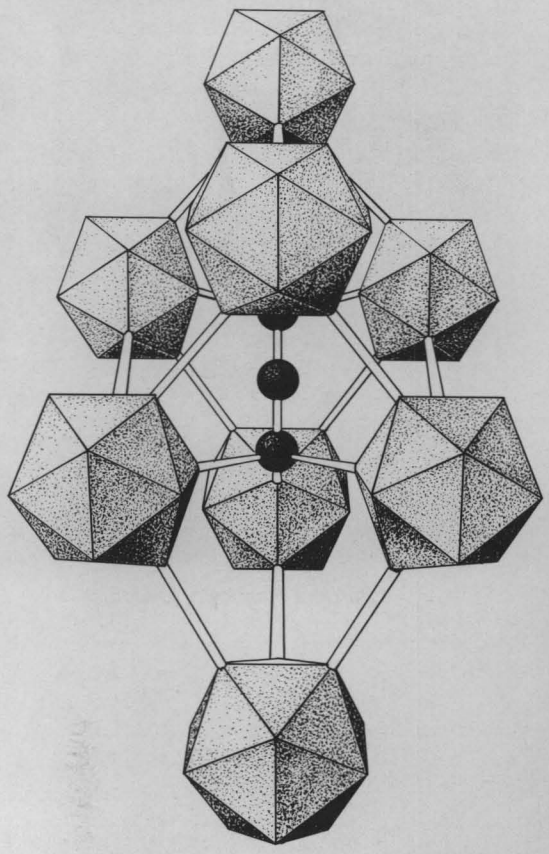
Barbara Hamkalo, biologist

Characterization of Boron Carbide

Although boron carbide (B_4C) has been known for a long time and is widely used as a neutron absorber in reactor control, understanding of the structural details of this compound has been inadequate to assure reproducibility of the quality needed for use in fast breeders. Oak Ridge National Laboratory has been applying x-ray diffraction and electron microscopy to gain a better understanding of boron carbide, both unirradiated and exposed to reactor neutrons. The crystal structure has been studied for some time, and last year ORNL metallurgists succeeded in measuring the lattice parameters to a precision better than one part in 25,000. The boron

atoms are in stable symmetrical groups of 12, and these groups are prominent in the microstructural behavior and irradiation performance of the material.

The boron carbide structure can be thought of as a three-dimensional lattice of B_{12} groups instead of individual atoms. Dislocations, the lines of mismatch that occur in all real crystals, involve these groupings rather than separate planes of atoms, so less energy is needed to expand areas of mismatch, and they can grow unusually large for nonmetals. The size and orientation of defects observed in irradiated samples indicate that the B_{12} groupings are retained as the boron atoms are removed by reactions with the neutrons; possibly the carbon atoms from the diagonal chains substitute for the missing boron atoms.



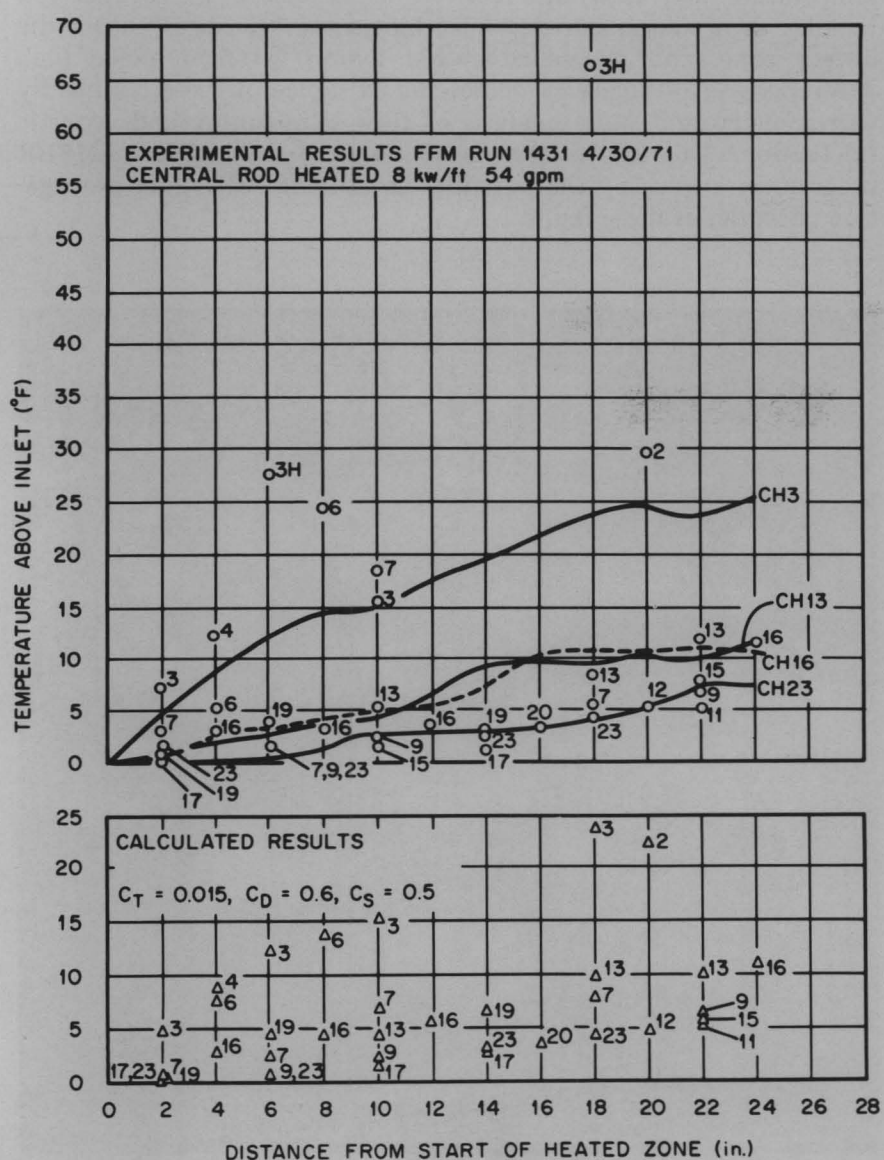
Crystal structure of boron carbide (B_4C). The boron atoms are arranged in icosahedra — highly symmetric three-dimensional groupings of 12. These icosahedra, in turn, are arranged in a rhombic solid, as shown. This rhombic pattern continues in all directions, with each icosahedron common to eight rhombohedra.

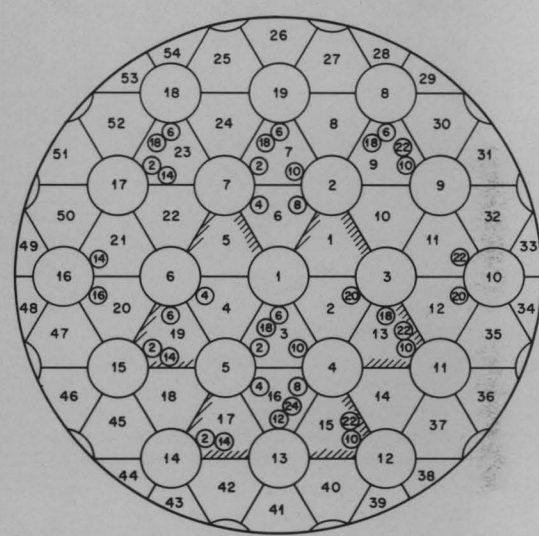
A rhombohedron may be thought of as a cube stretched along one diagonal, and in this structure the three carbon atoms are in a line on that diagonal.

Electron micrograph of boron carbide, magnified 22,500X, showing lines of mismatch that disappear under neutron irradiation.

Fuel Failure Mockup

Potential safety problems are being considered very early in the development process of the LMFBR to assure that safety is inherent in the plant rather than an afterthought. ORNL's contribution to this effort is centered on the Fuel Failure Mockup (FFM) Program — a coordinated effort to determine experimentally those factors that might lead to fuel failure and fuel failure propagation. It was under this program that the Fuel Failure Mockup facility was built and placed in operation in 1970. It is an engineering-scale sodium loop in which fuel bundles simulated by electrical heaters are subjected to conditions quite similar to those expected in a real reactor. The heaters have the same size, pitch, spacer geometry, and power rating as the fuel pins for the Fast Flux Test Facility (FFTF), a 400-MW(t) reactor now being built at Hanford.





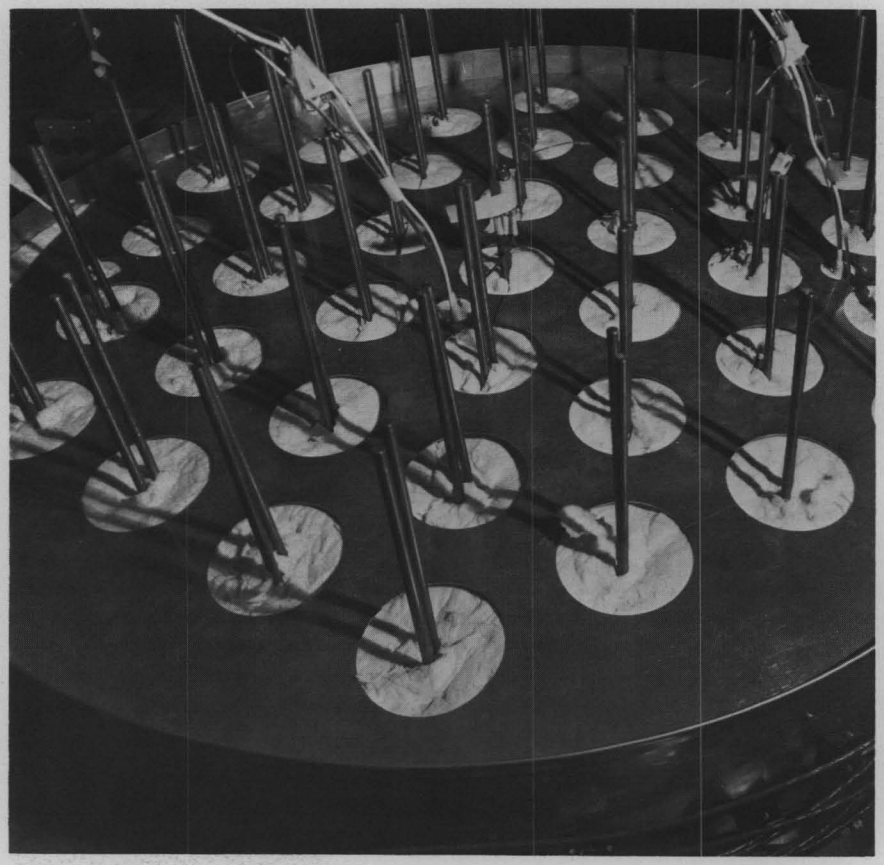
Temperature distribution in the simulated fuel rod bundle. Experimentally determined points are shown in the upper plot and the analytical predicted temperatures at these same positions are shown in the lower plot. The lines show the predicted continuous temperature along selected channels. The numbers alongside the points refer to the channel position as indicated above.

Edith Halbert, physicist

The first experiments helped to determine the flow mixing characteristics of the FFTF fuel bundle. By running with the central pin heated only, the heat transferred to the sodium could be viewed as a tracer. The transport of heat throughout the bundle indicates the flow mixing taking place. Knowledge of the flow mixing is essential to the plant designers so that they may take proper precautions to prevent fuel bowing due to temperature variations within the bundle.

The initial work has emphasized the ability to analytically model the actual temperature distributions as measured by thermocouples, two of which are placed within each 0.056-in.-diam wire wrap spacer. The analytical predictions are based on a computer code written at ORNL for actual thermocouple positions. Considering that flow in rod bundles is not well understood, the agreement between model and experiment is very good. The code with experimentally determined constants can be used to calculate flow and temperature within full-scale fuel assemblies.

The FFM will be used in the near future to determine the temperature and flow distributions in simulated FFTF fuel rod bundles as a consequence of inlet blockages, blockages within the heated zone, and release of stored fission gas from failed fuel. Attempts will be made to detect the existence of these failures by thermometry and noise analysis of flow temperature and acoustic fluctuation. This information is of value to the national LMFBR program in evaluating the potential hazard and the failure propagation potential of these faults.



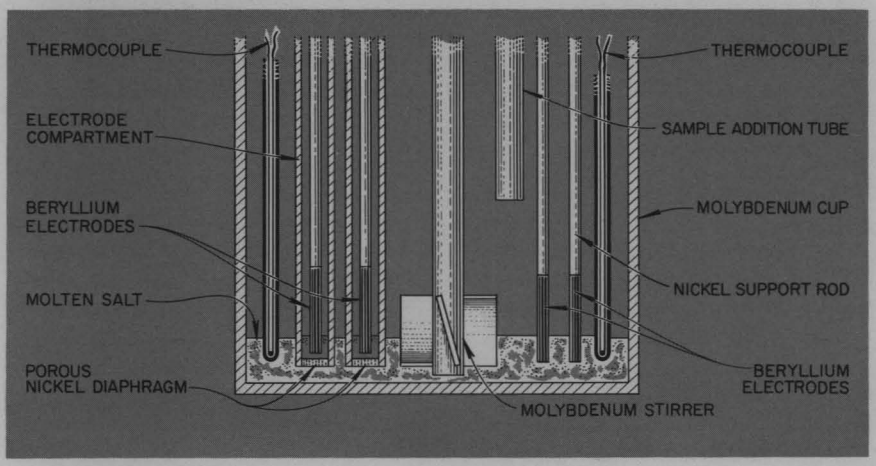
Experimental fuel bundle using electrical heaters to simulate fuel rods.

Molten-Salt Breeder

The Electrodynamics of Lithium Fluoride—Beryllium Fluoride Mixtures

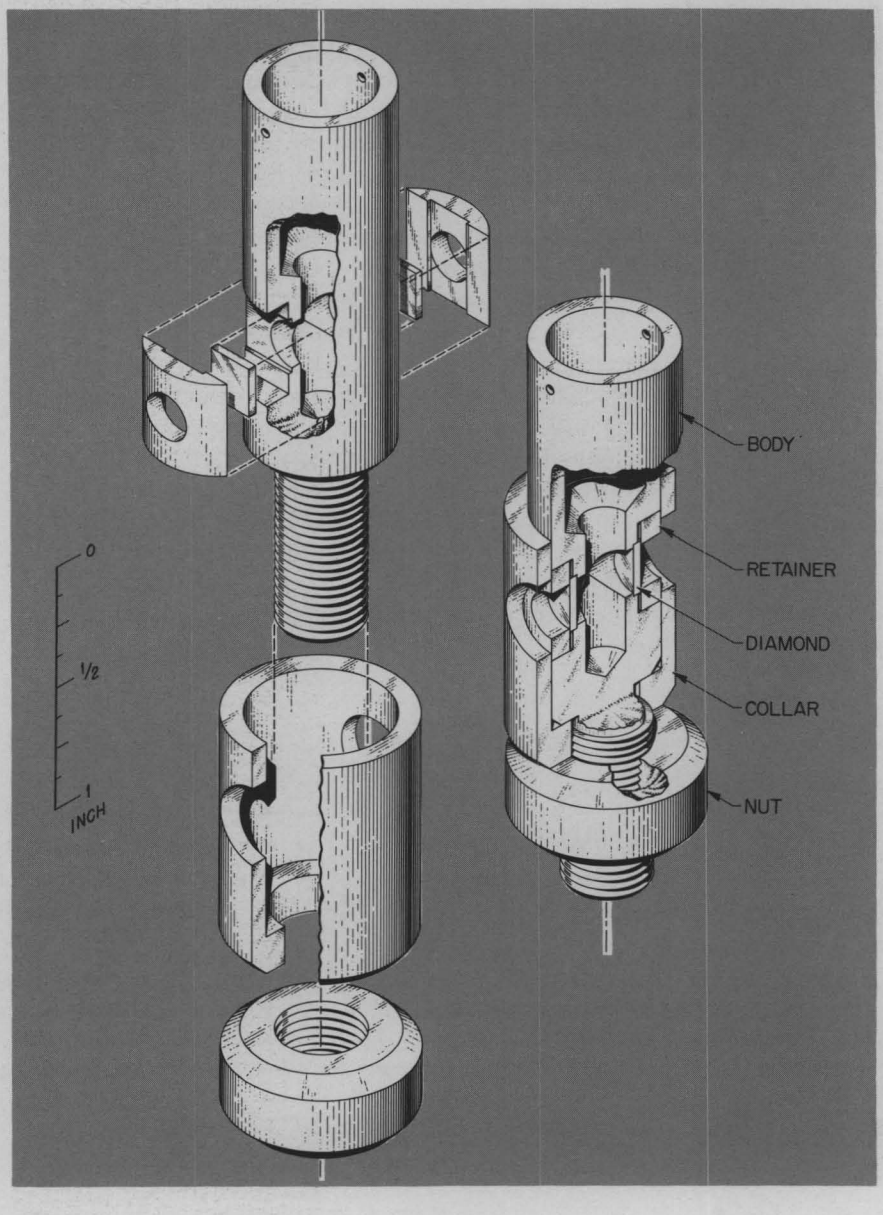
Lithium fluoride and beryllium fluoride are important constituents of molten-salt nuclear reactors. Their molten mixtures have been used in the Molten Salt Reactor Experiment at ORNL and proposed for the breeder as the solvent for the fissioning fuel. In the course of electrochemical studies on how a current can be made to flow through these molten salts, a number of unusual and interesting physical and chemical properties have recently come to light.

An all-metal cell of nickel and molybdenum was designed to measure the electromotive force generated by a pair of beryllium metal electrodes dipping in different liquid mixtures of lithium fluoride and beryllium fluoride, separated by a porous nickel diaphragm. This permits a calculation of what fraction of the current is carried by the lithium ions and what fraction by the beryllium ions in the melt. In most molten salt mixtures through which an electric current is made to flow, the ions constituting the salts migrate very nearly in proportion to their relative concentrations. The results for lithium fluoride—beryllium fluoride mixtures, however, showed that over a wide range of concentrations only one of the two kinds of positive ions (lithium) migrates relative to the negative ion (fluoride). This phenomenon, called a *unicationic conduction mechanism*, occurs also in molten silicate glasses and is consistent with other similarities in structure and behavior that have been observed between silicates and alkali fluoride—beryllium fluoride mixtures. It is significant in that it suggests that such mixtures might prove useful in certain kinds of electrical switching devices for operation at elevated temperatures.



Electrochemical cell for determination of electrical transference numbers in molten lithium fluoride—beryllium fluoride mixtures.

X-RAY DIFFRACTION OF GRAPHITE *Burl Cavin examines a sample of graphite on an x-ray diffractometer. The instrument is used to determine lattice parameters and crystallite sizes in graphite being considered for use in molten-salt reactors. This helps to judge its stability under reactor radiation. Cavin's instrument, and the diffractometer in the right background, are operated simultaneously by the computer in the tall black box behind Cavin. The x rays reach the sample from the left through an ORNL-developed monochromator. The teletypewriter then records the data on paper tape for computer analysis. The instrument in the background is for measuring the preferred orientation of individual crystals, i.e., the texture, of metals.*



MOLTEN SALTS THROUGH A DIAMOND WINDOW *Diamond-windowed cell for spectrophotometry of molten fluoride salts. A small optical cell utilizing $^1/_2$-carat diamond plates has been fabricated for the study of molten fluoride solutions, because diamond is the only known window material that can withstand the corrosive attack of fluorides at temperatures up to 900°C. Through the use of this cell, changes in number and position of fluoride ions around dilute uranium(IV) ions have been identified and related to the characteristics of the solvent media. This detailed description of uranium(IV) is of importance in understanding its behavior as a fuel in molten-salt reactors.*

Gas-Cooled Reactor

Margaret Clarke, psychologist

Coated Particles for Fuel

A new type of coated-particle fuel with better performance was developed at Oak Ridge National Laboratory in 1970. High-temperature gas-cooled reactors are fueled with spherical particles sealed by a layer of deposited carbon to prevent escape of fission products. The new fuel is made by soaking tiny beads of ion exchange resin with uranium solution and heating the beads at 2700°F in an unreactive gas. Several advantages over the uranium carbide fuel for the Fort St. Vrain Reactor are evident. Chemical conversion steps are avoided, since the fuel is made from solutions like those from reprocessing plants. Because the particle is porous, it does not need a thick layer of spongy carbon under the sealing layer to accommodate the swelling that fuels undergo during fission; only a layer less than a thousandth of an inch thick is needed to protect the sealing layer from high-energy fission products. These changes in fabrication processing reflect a significant saving to the overall fuel recycle cost.

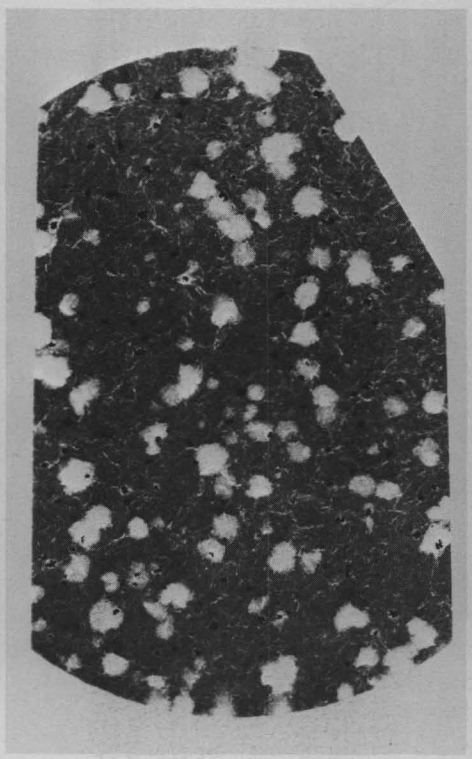
The new coated particles are approximately the size of crystals of table salt.

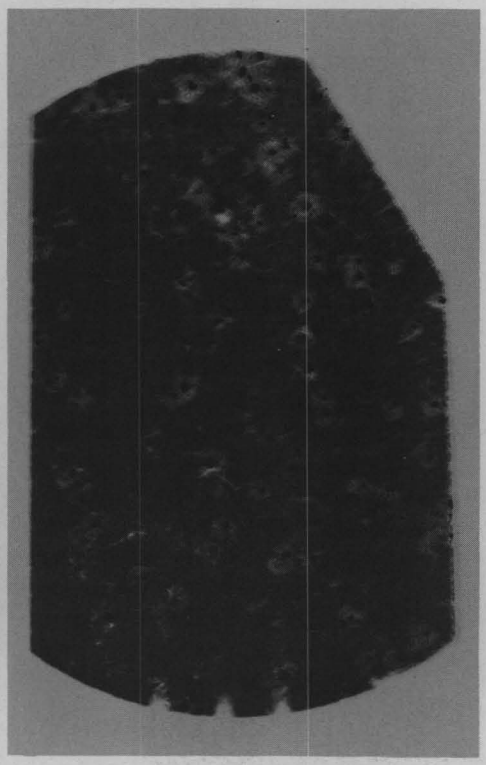
Alice Hardigree, biologist

A striking advantage of the new fuel is its performance in a temperature gradient. The intense heat production in nuclear fuel can result in sharp temperature variations across a fuel element. When the new fuel was heated to about 3300°F with a temperature varying more than 300°F across the 0.01-in. diameter of a fuel particle, no fuel migration (less than 0.0001 in.) was detected. Conventional uranium carbide (UC_2) particles in the same experiment completely penetrated coatings 0.005 in. thick.

Ion exchange resins are relatively inexpensive plastic-like materials that can exchange some constituents with dissolved inorganic substances in water. They are widely used in water treatment. In the atomic energy program they are used to separate actinide elements and fission products and to concentrate fissile materials from processing plant streams and natural sources.

IMPURITY CATALYSIS OF THE STEAM-GRAPHITE REACTION *X radiographs of some types of commercial graphite show fairly large, highly localized regions of high metallic impurity content (left). When this type of graphite is exposed to steam at elevated temperatures, the steam-graphite reaction proceeds by a pitting mechanism; that is, the reaction proceeds extremely rapidly only in specific regions of the graphite specimen, as seen in the x radiograph (center). By superposing the radiographs of the sample before and after reaction (right), it is readily seen that the areas of pitting formerly were sites of high impurity content. A more surprising observation, however, is that the catalyst appears to have become somewhat mobile through the act of catalysis, and is thus no longer visible by x radiography (center).*





Light-Water Reactor

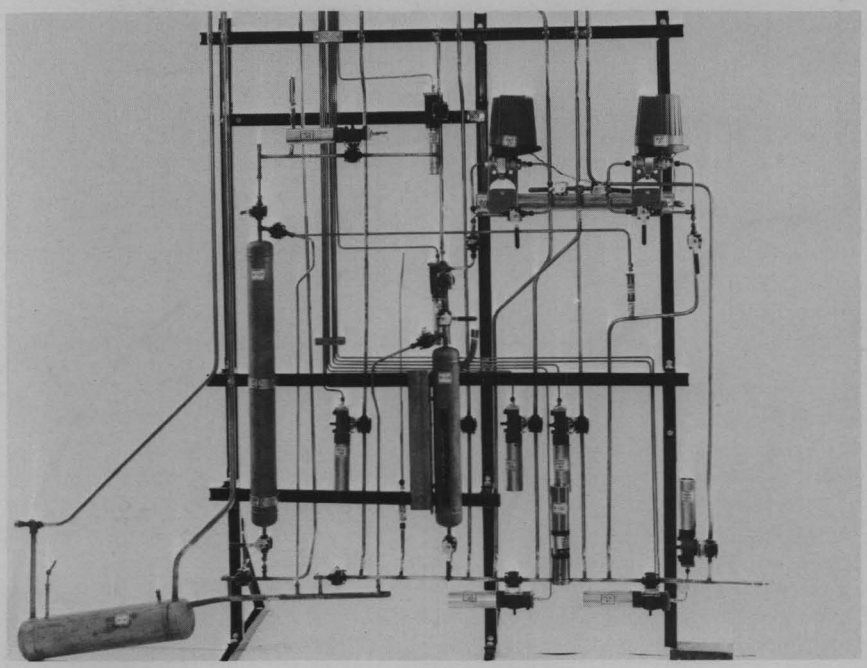
Norma Buhl and Barbara Bishop, mathematicians

Preparation of Uranium Dioxide from Uranium-233

Oak Ridge National Laboratory, under contract with the Bettis Atomic Power Laboratory (BAPL), will provide several hundred kilograms of uranium-233 in the form of freshly purified ceramic-grade UO_2 for use in the Light-Water Breeder Reactor Program.

The feed material has been received from the production plants and stored in newly constructed storage facilities. The original Thorex pilot plant in Building 3019 has been updated and will serve as the solvent extraction purification system. A high-pressure ion exchange system, with a capacity of 20 kg of uranium-233 per 18 hr of operation (including regeneration), has been developed, designed, and installed. This system, which is intended primarily to remove the final traces of thorium from the uranium-233 solution, will provide adequate decontamination from the daughter activity to permit the oxide conversion step to be carried out in unshielded equipment. A major portion of the feed material will meet ionic specifications for the final UO_2 powder and can be fed directly to the ion exchange system, bypassing the solvent extraction pulsed columns.

A UO_2 conversion glove-box line having a capacity of 20 kg/week and using the ammonium uranate technique for precipitat-



Solutions of uranium-233 containing about 100 g of thorium-228 per liter enter this ion exchange array on the lower right, traveling up through the center tank and across and down through the long tank on the left. The tanks contain ion exchange resin particles, on which the minute quantities of thorium remain, purifying the uranium at the rate of a liter per minute. The thorium isotope has high-energy daughters, which decay after a few days. The purified uranium can be handled in a glove box without shielding. In 25 days, however, enough thorium has again formed to require a repetition of the process.

ing the uranium is being designed. After fabrication, it will be installed in an existing alpha laboratory, adjacent to the processing cells. The feed solution will be precipitated with ammonia gas, and the precipitate will be separated from the mother liquor in a bowl-type centrifuge containing a removable liner, which is subsequently placed in a microwave oven for drying. The material will then be transferred into a continuous-belt furnace and reduced in hydrogen. Stabilization of the powder will be attained on a vibrating chill plate.

The final UO_2 powder will be blended in 20-kg lots and shipped to BAPL, where it will be blended with ThO_2 in concentrations ranging from 0.9 to 6% UO_2.

The pellets that are rejected by BAPL will be returned to ORNL for dissolution and recovery in the solvent extraction plant.

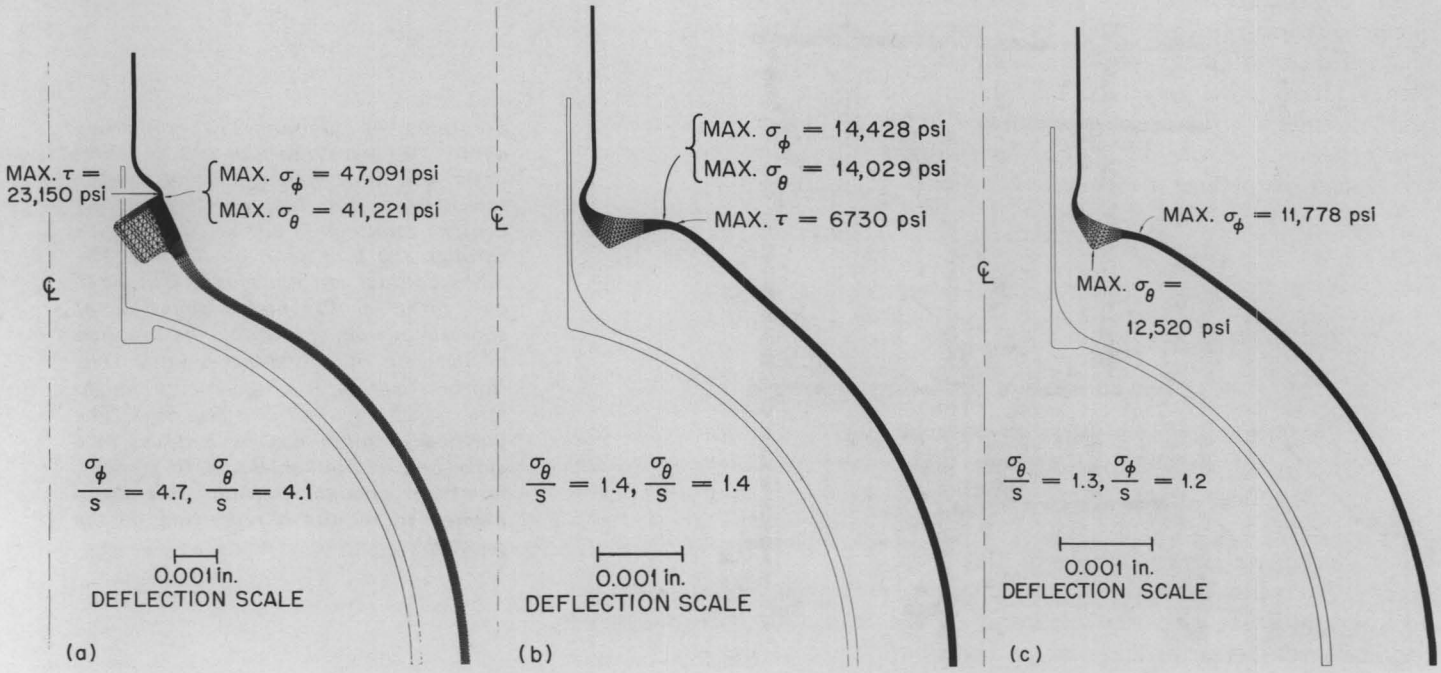
Parametric studies to determine the effects of variations in flowsheet conditions on the quality of the final UO_2 powder are being made.

The entire system is expected to become operable in late 1971. Routine production is scheduled to begin in early 1972.

Nozzle Reinforcement on Pressure Vessels

The design of nozzle penetrations in nuclear pressure vessels has relied largely on the so-called area replacement rule for reinforcement. This rule stipulates that the amount of material being removed from the vessel in forming the opening must be replaced in the form of nozzle reinforcement. Nuclear vessels designed using this

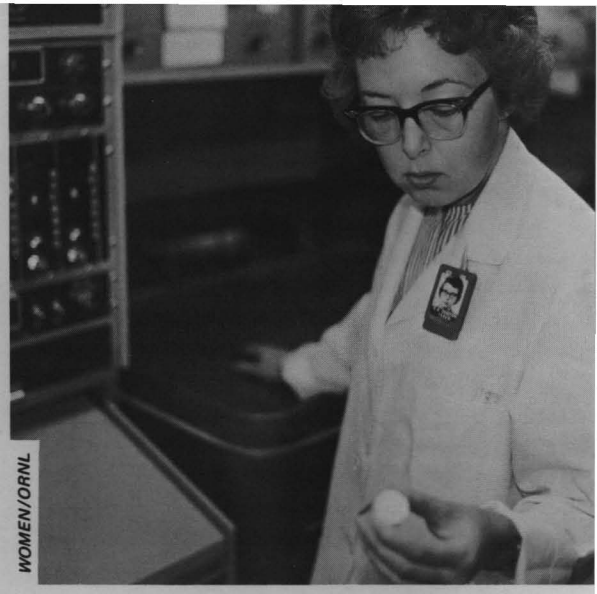
Results of a finite-element analysis of compact nozzle reinforcement are shown in the form of computer-generated plots of undeformed and deformed cross sections of the nozzle-to-vessel attachment region. Three types of reinforcement of a relatively thin-shell model are illustrated: (a) *100% inside reinforcement,* (b) *100% outside reinforcement, and* (c) *balanced combination of 65% outside and 35% inside reinforcement. These percentages are based on the cross-sectional area of material removed to form the opening in the vessel. The deformed cross sections shown on the right are divided into the basic triangular ring elements used in the analysis. The actual deformation has been exaggerated to show the mode of deformation clearly. Also indicated on the figures are the maximum stresses — circumferential (σ_θ), meridional (σ_ϕ), and shear (τ), as well as the ratios of these maximum stresses to the membrane stress (s). By comparing the maximum stresses and stress ratios for the three reinforcement types, one can see the advantage of using either outside reinforcement or reinforcement balanced between the inside and outside.*



rule have in general performed satisfactorily; however, the few reported problems have been associated with nozzles or openings. The trend toward use of high-strength materials and higher design stresses, plus the increased reliability demands of nuclear vessels, have intensified the need for a better understanding of the behavior of reinforced openings in pressure vessels. An investigation of the relative effectiveness of various reinforcement configurations at the juncture of radial nozzles with spherical pressure vessels was undertaken by ORNL last year. The purpose of this investigation was to determine the applicability of the present code area replacement rule to the design of nozzle compact reinforcement placed inside the vessel. Compact reinforcement is located close to the point of attachment of the nozzle to the vessel and is frequently in the form of a relatively large-radius fillet located on the vessel's outer surface.

A parametric analytical study was made using the finite-element method to investigate the effectiveness of reinforcement located either inside, outside, or balanced between inside and outside surfaces of the vessel. Both relatively thin-shell and thick-shell models have been analyzed. The finite-element analysis used in the study was developed by Gulf General Atomic, Inc., and modified at the Oak Ridge Computing Technology Center. It is based on a two-dimensional axisymmetric solid body formulation.

Examples of the results obtained in the study of a relatively thin-shell model are shown in the figure. In each of the three cases illustrated in the figure, the undeformed cross section of the nozzle-vessel attachment is shown as a line drawing. To the right of each line drawing is a computer-generated finite-element representation of the deformed cross section resulting from internal pressure loading. In the case of the model with inside reinforcement, the cross section appears to rotate outward, while the model with outside reinforcement rotates inward. The model with balanced reinforcement deforms by means of outward displacement only. By using inside reinforcement exclusively, the maximum stresses remain high when compared with the unreinforced model; however, by using either outside reinforcement or a balanced combination of outside and inside reinforcement the maximum stresses are reduced significantly. It can be concluded from this study that inside compact reinforcement should be used only in combination with outside reinforcement in order to provide the factor of safety required for the design of nuclear pressure vessel nozzle attachments.



Barbara Chastain, biologist

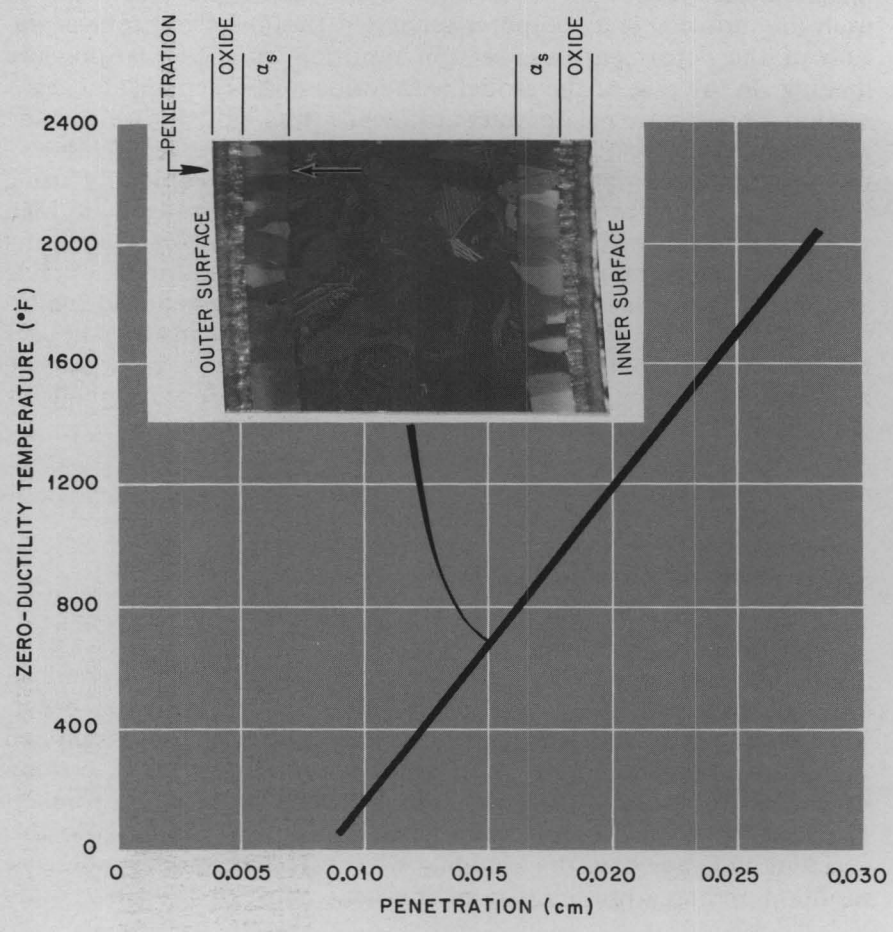
Safety Study on Zircaloy Cladding

In light-water-cooled reactor systems it is considered credible, although highly unlikely, that a loss-of-coolant accident can occur. The consequences of such an accident have, however, been examined in considerable detail, and ORNL has been responsible for a portion of the analysis concerned with the behavior of the fuel element cladding. Hydraulic and thermodynamic calculations related to this accident indicate that the cladding of the fuel rods will undergo a resultant temperature increase or transient. Most of the early, rapid

Shigemi Simms, biologist

temperature rise of the cladding is a direct result of redistribution of the heat content of the UO_2 fuel. After this redistribution is accomplished, the major driving force for temperature increase is the heat generated by decay of the fission products within the fuel rods. Finally, the chemical reaction between the zirconium alloy fuel cladding (Zircaloy) and steam formed either from the original coolant or emergency cooling water is exothermic and can also add to the transient temperature rise.

As the cladding-steam reaction proceeds, oxygen penetrates the cladding tubes and diffuses inward. The structure formed in the tubing wall as a result of this reaction and diffusion consists of zirconium oxide on the outer surface, a region of oxygen-stabilized α phase (α_s) immediately beneath the oxide, and, below this, β-phase material, which reverts to normal α phase on cooling below ~1500°F. Only the material in this second region has the capability to undergo plastic deformation; the oxide and α_s phase are brittle up to extremely high temperatures. Therefore, if a substantial fraction of the cladding wall is converted to oxide and α_s during the loss-of-coolant transient, it is certainly to be expected that the fuel cladding will be embrittled. There are two major concerns in this regard. Assume that an accident has occurred and the temperature transient undergone and then terminated by emergency cooling. Will the fuel cladding retain sufficient ductility to permit removal of the fuel assemblies intact? (Removal of a partially disintegrated core



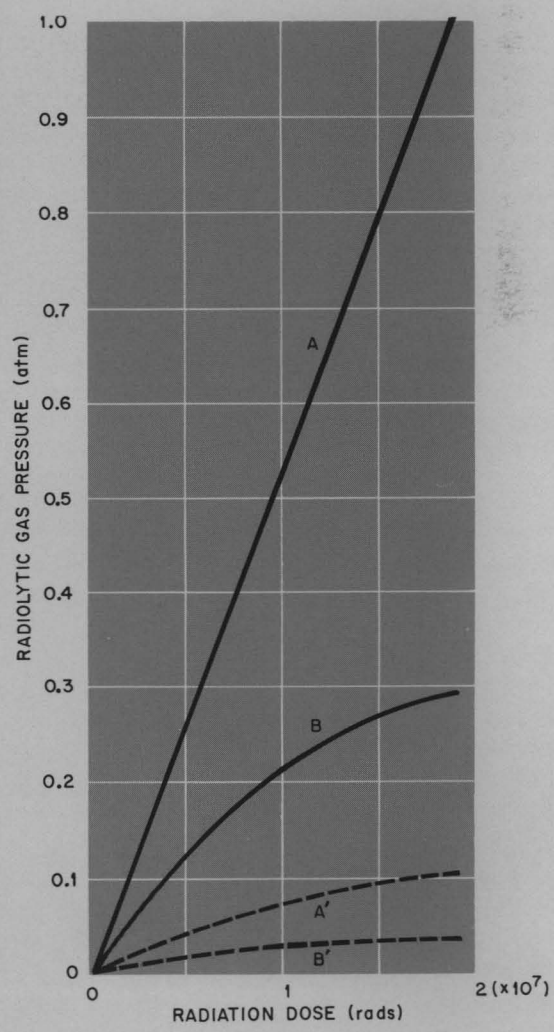
The temperature below which pressurized-water reactor fuel cladding supports no plastic deformation prior to fracture, the zero-ductility temperature, depends upon the depth of penetration of the oxide and oxygen-stabilized α-phases (ZrO_2 and α_s). The inset shows the microstructure across a tube wall which has a zero-ductility temperature of ~700°F. Penetration is 0.015 cm from each surface. This particular microstructure was produced by a 4-min exposure at 2400°F. Equivalent structures could be attained by an infinite number of other time-temperature combinations.

would be extremely complicated and expensive.) Will the fuel cladding retain sufficient ductility to prevent disintegration during the period of emergency coolant addition? (Little is known of how this would affect transient termination.)

Last year, to examine these questions, ORNL engineers exposed Zircaloy cladding tubes to steam at a series of temperatures from 1700 to 2500°F. The tubes were allowed to react on their inner as well as the outer surface. This is a realistic simulation of what will occur during the loss-of-coolant accident transient; temperatures in excess of 1700°F will result in rupture of the cladding — the internal fission gas pressure will exert a stress higher than the rupture strength — and thereby expose both surfaces to steam. Subsequent to exposure of the cladding specimens, rings were machined from the tubes and stressed at a high rate under compression along their radius. These tests, conducted in an inert atmosphere at temperatures to 2000°F, yielded a correlation between zero-ductility temperature (the temperature below which the specimens will undergo no plastic strain before brittle fracture) and the depth of penetration of the oxide and α_s phases.

The penetration measured after isothermal exposure to steam increases directly with time to the one-half power, $t^{1/2}$. The slopes of the penetration-$t^{1/2}$ curves can be fitted to an equation containing temperature as the variable, and the resultant equation can be integrated to evaluate penetration for any given loss-of-coolant accident temperature history. Application of this method of analysis to calculated transients for reactors now in operation or under construction indicates that the zero-ductility temperature of the cladding will be below ambient temperature and that sufficient ductility will exist to permit transient cooldown and core removal without significant breakage of the fuel rods. However, this conclusion may be unconservative in that it neglects the decrease in cladding wall thickness that accompanies deformation prior to rupture, and additional work is indicated.

The generation of radiolytic hydrogen can be greatly reduced by the addition of 2.0×10^{-3} M $NaVO_3$ to both 0.15 N NaOH + 3000 ppm B (curve A) and 3000 ppm B (curve B) spray solutions. The results shown were obtained in a dynamic loop operating at 65°C with an air cover gas, 0.2 gas-to-liquid ratio. The presence of the additive (curves A′ and B′) causes a tenfold reduction in the radiolytic gas pressure.



Cleaning the Post-Accident Atmosphere

The safe operation of a nuclear plant under normal or accident conditions is a primary goal of those associated with the development of nuclear power. The reactor containment spray system — one of the several engineered safety features included in modern nuclear power stations to mitigate accident conditions — is designed to reduce the building pressure by condensing the steam released in a primary coolant line rupture and to remove released fission products. A four-year program at the Laboratory, completed in 1970, included basic chemical and aerosol research as well as pilot plant experiments. It succeeded in developing the technology necessary to gain wide acceptance of spray systems as a fission product removal device as well as a pressure suppression device.

Of the many fission product species involved, the spray program was specifically concerned with the removal of elemental iodine, methyl iodide, and particulates. At the very low mass concentrations expected in reactor containment buildings following the design basis accident (100% of the iodine in the atmosphere gives concentrations

Claudia Lever, statistician

of the order of 10^{-7} mole/liter), the distribution of the iodine between the atmosphere and spray solution strongly favors the liquid. Hence absorption of elemental iodine should be gas film controlled. The distribution of hydrogen iodide even more strongly favors the liquid phase. Methyl iodide is slightly soluble in water and moderately reactive; hence its removal mechanism is liquid-film-controlled absorption followed by pseudo-first-order reaction in the liquid phase. Some ten discrete physical processes are involved in removing particles by sprays. However, it has been found that processes which are related to steam condensation predominate and that there is a direct relationship between particle removal and steam condensation.

The program also determined that elemental iodine will be removed very rapidly and that particles will be removed at a sufficient rate to reduce slightly the dose attributable to activity associated with particles. A significant reduction in the dose attributable to methyl iodide for short times after the accident is unlikely with present solutions; however, a measurable reduction in the methyl iodide dose contribution over longer time periods is to be expected.

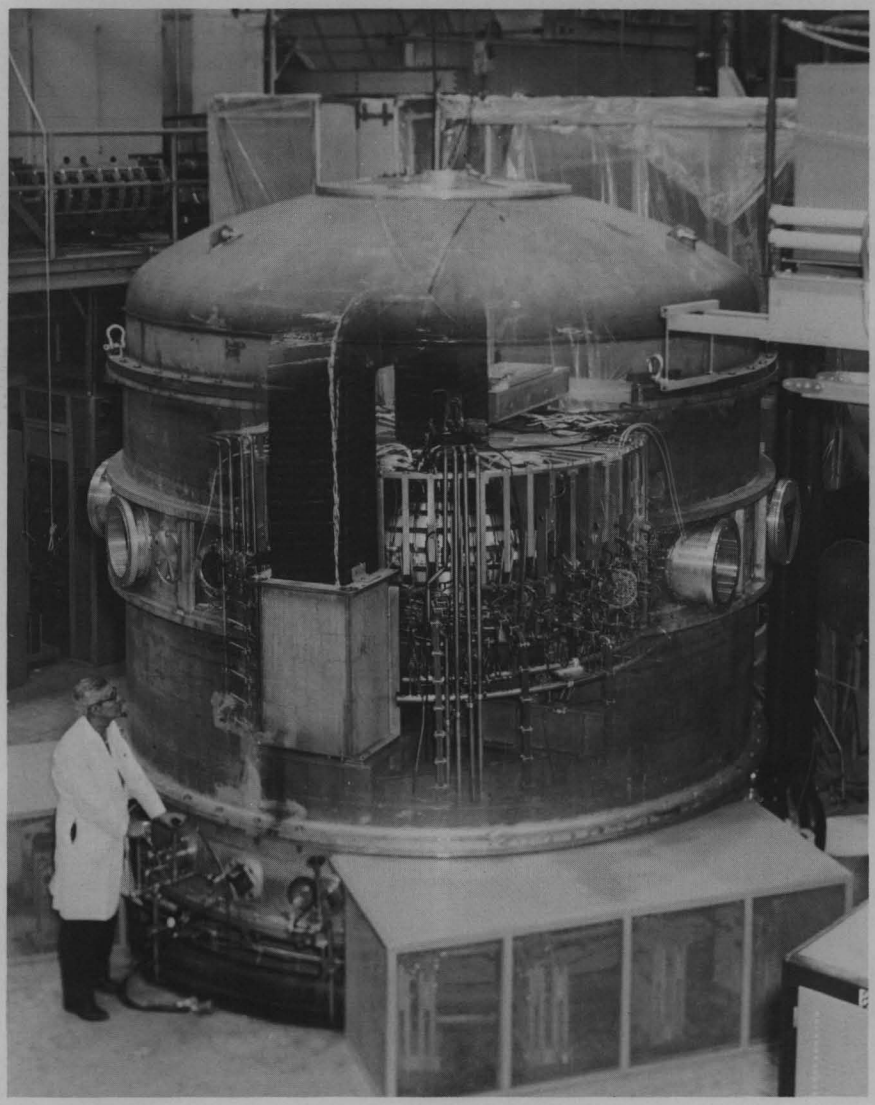
The spray solution, as well as all of the post-accident coolant, will be exposed to extremes of radiation (up to $\sim 3 \times 10^8$ rads) and temperature ($\sim 130°C$). Tests with various solutions established that some are seriously affected while others demonstrate reasonable stability. During these studies it was also demonstrated that the generation of radiolytic hydrogen is sufficient to be considered a hazard in the accident case for both pressurized and boiling-water reactors. It was found that in a dynamic system using both the most widely accepted spray solutions, the radiolytic hydrogen buildup can attain concentrations on the order of several atmospheres with no equilibrium state being attained. Since it is assumed that any hydrogen concentration over about 4 vol % can be potentially dangerous, it is readily seen that concentrations an order of magnitude higher will be a definite hazard to the integrity of the reactor containment. Due largely to data generated in this program it has become axiomatic that some engineered safety features be provided to eliminate the danger from hydrogen buildup due to radiolysis and other hydrogen-producing reactions. Various types of recombiners and methods for removing hydrogen have been proposed. In this program, studies have been made on the use of various additives to the spray solution to minimize the evolution of radiolytic hydrogen. The most successful reagent found to date is sodium metavanadate ($NaVO_3$). Addition of this compound has been found to decrease radiolytic hydrogen generation by an order of magnitude in several of the proposed spray solutions tested.

The effects of the addition of $NaVO_3$ to several of the proposed spray solutions are shown. The graph shows the buildup of radiolytic gases (H_2, O_2) as a function of absorbed radiation dose. It can be seen that in the absence of the reagent $NaVO_3$ the radiolytic gases build up at a rate an order of magnitude faster than when it is present. Translation of the radiolytic gas pressure to volume percent present (0.05 atm would equal approximately 5 vol %) shows that in the case of both sprays a dangerous level of radiolytic H_2 is easily attained.

Controlled Fusion

ORMAK

The ORMAK (*O*ak *R*idge Tok*amak*) experiment at the Laboratory was constructed in 1970. Experiments are under way to extend to higher values the highly successful operating regime of the Russian Tokamak experiments and to explore new heating methods that should increase the ion temperature in these devices to nearly fusion levels. This photograph is a composite showing the external vacuum

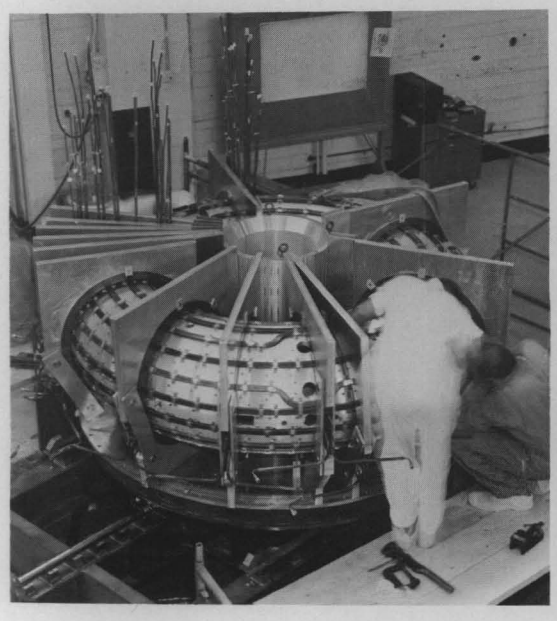


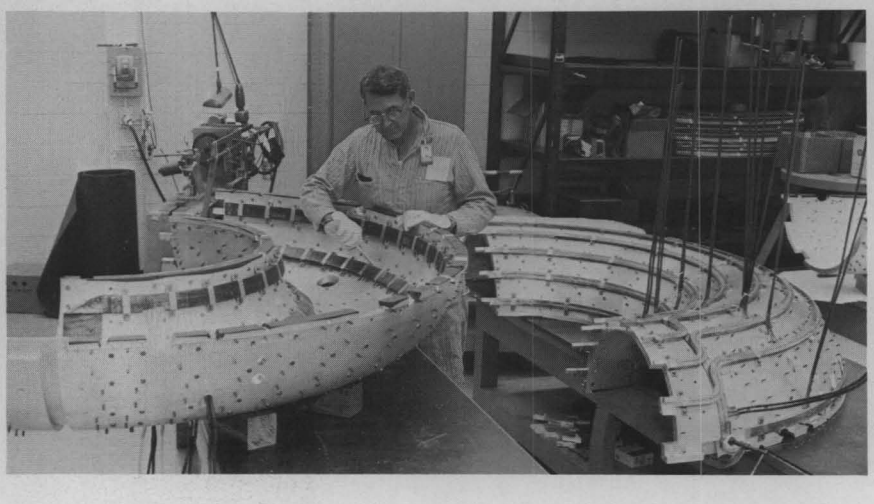
Composite photograph showing the interior and exterior of ORMAK, the Oak Ridge Tokamak, in the Thermonuclear Division's experiments in controlled fusion. The ORMAK ran in 1971 without mishap for about two months, after which it was closed down for a month for further modifications in its design. In its present run, cooled to 77°K (—196°C) to triple its magnetic field, it is expected to demonstrate by spring of 1972 a definite trend toward feasibility.

Kathren Stelzner, biologist

tank and the usually hidden internal region in which the plasma is contained. The large cylindrical, vertical vacuum tank surrounds the plasma region and provides for the plasma purity necessary for successful operation. Showing through this vacuum tank is the doughnut-shaped plasma region that is formed by the toroidal configuration of magnets and a transformer core. The plasma is contained in the region near the center of the photograph, though it cannot be seen in this photograph. The vacuum tank, in addition to providing the necessary vacuum, also contains large ports at the left- and right-hand sides of the picture; they are provided for future heating techniques that utilize the injection of energetic ions to raise the established plasma to higher ion temperatures. There are three magnetic fields that are used to contain and control the Tokamak plasma. The main magnetic field is created by current flowing in 56 coils. These coils appear as spokes radiating from the transformer core in the center of the photograph. This field is approximately 25,000 G (50,000 times the earth's magnetic field). The transformer seen in this photograph as a large, inverted "U" threads the center of these coils and serves the function of creating a 400,000-A current by induction in the center of these 56 coils. This current first creates the plasma and then heats it by friction to very high temperatures, but it also serves a second crucial function in that it creates the second important magnetic field, which is perpendicular to the main magnetic field. The combination of these two fields produces a twist which prevents the rapid escape of plasma particles due to electric fields that are otherwise developed. Finally, coils not seen in the photograph produce a third small but vital magnetic field that is perpendicular to the other two and provides a fine tuning to locate the plasma in suitable positions for stable confinement. Proper cooling of these magnetic fields is provided by liquid nitrogen, which is controlled by the valves that the man in the photograph is turning. The large current leads which provide current to the coils to create the essential magnetic fields are hidden by the large rectangular boxes in the lower right-hand corner and lower left-hand corner and come from four motor-generator sets providing 30 MW of power. Additional ports are available to diagnose the plasma and to locate and measure the plasma parameters, such as density, temperature, and lifetime.

Stages in the construction of ORMAK. Fabrication of the aluminum torus that will hold the plasma is performed by Steve McFarland, right.



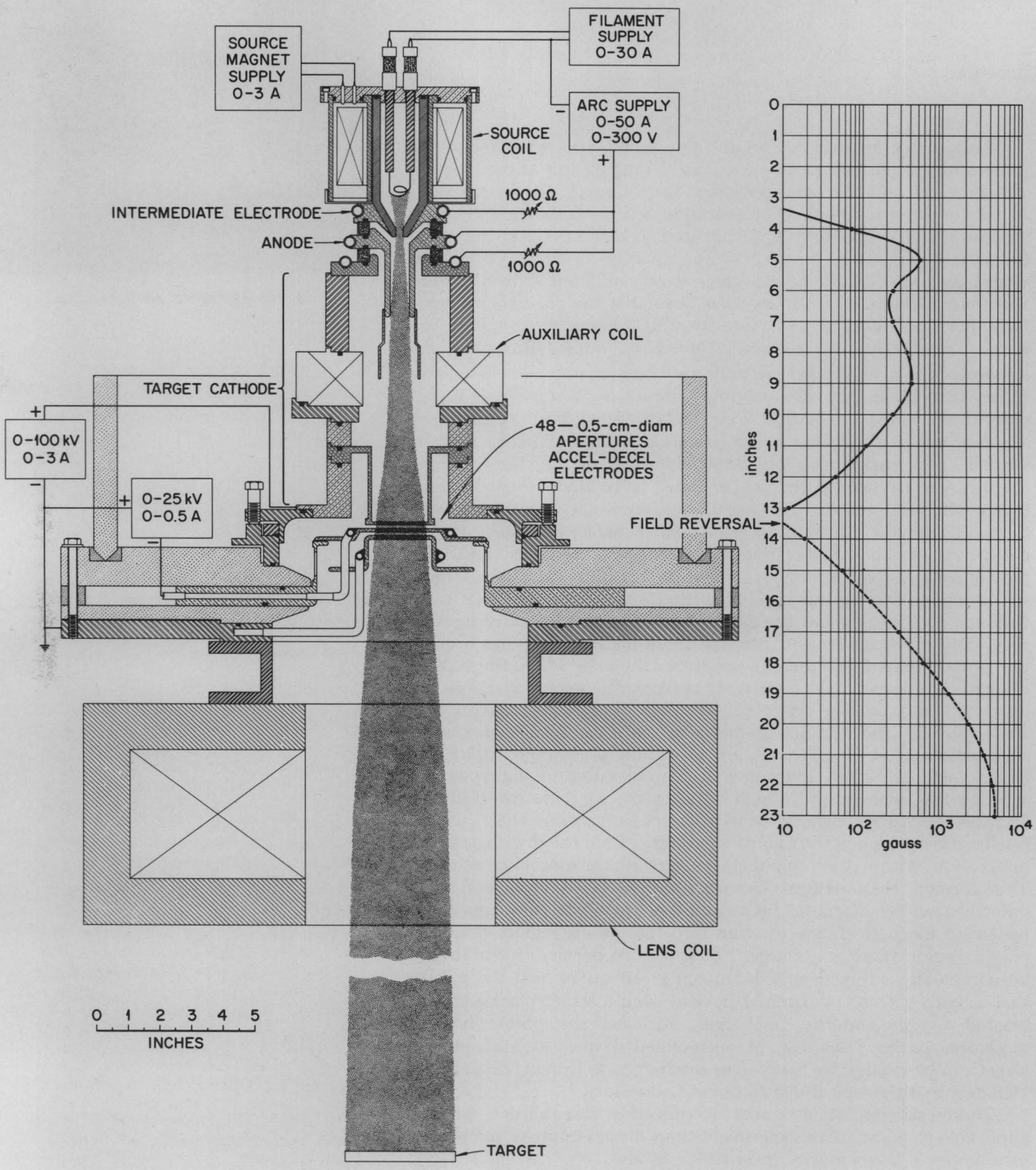


Injection

Perhaps the most powerful and universally applicable technique for producing plasmas in any magnetic configuration at the high ion temperatures and densities necessary for abundant fusion reactions to take place is the method of neutral injection. In this method, ions are created in an ion source, accelerated to high energies, converted to neutrals, and then directed to the appropriate plasma container where they are captured and their energy utilized. The difficulty with this technique in the past has been that the currents available have been inadequate to create the high densities and high ion temperatures that are necessary. However, during this year, the Laboratory has developed ion sources whose currents are ten times higher than those that were previously available. We now have 2 A of current at energies of 30,000 V in a suitably small beam so that they are now useful for filling many plasma containers. This substantial advance now makes possible even new areas of use; for example, these beams are now in the proper range to be able to heat to much higher temperatures the existing plasmas in closed geometries, such as in Tokamaks. They are also now capable of filling mirror containers to much higher densities and higher energies than were previously possible. Examples of mirror containers that lend themselves well to such an approach are the IMP device at the Oak Ridge National Laboratory and the 2X-II device at the Livermore Laboratory. The chief advance in creating these high currents has been in the proper shaping of the ion source in the area where the intense discharge of an arc takes place. It is from this region that ions are extracted and later accelerated. Through the proper spacing and shaping of electrodes in this discharge region it has now been possible to increase the area of the region to be able to extract from much larger surfaces. When extracted and accelerated to high energies through the application of high voltages the ions are directed and focused by strong magnetic fields that act as lenses so that the ions can be directed along the axis of a cylindrical cell filled with gas. The interaction within this cell then converts these ions into neutrals. Thus formed, these neutrals can drift over large distances, and being uninfluenced by magnetic fields and electric fields they can easily penetrate magnetic fields to enter into the plasma region. If in this plasma region there is a "target" of sufficient density this beam can be completely stopped and its energy given up to heat the plasma that already exists. In toroidal devices such a target plasma can be created by the intense discharges, such as the ohmic heating discharge in the Tokamak. In open-ended devices such an intense target can be created by microwave discharges, as is being done in the IMP device at the Oak Ridge National Laboratory.

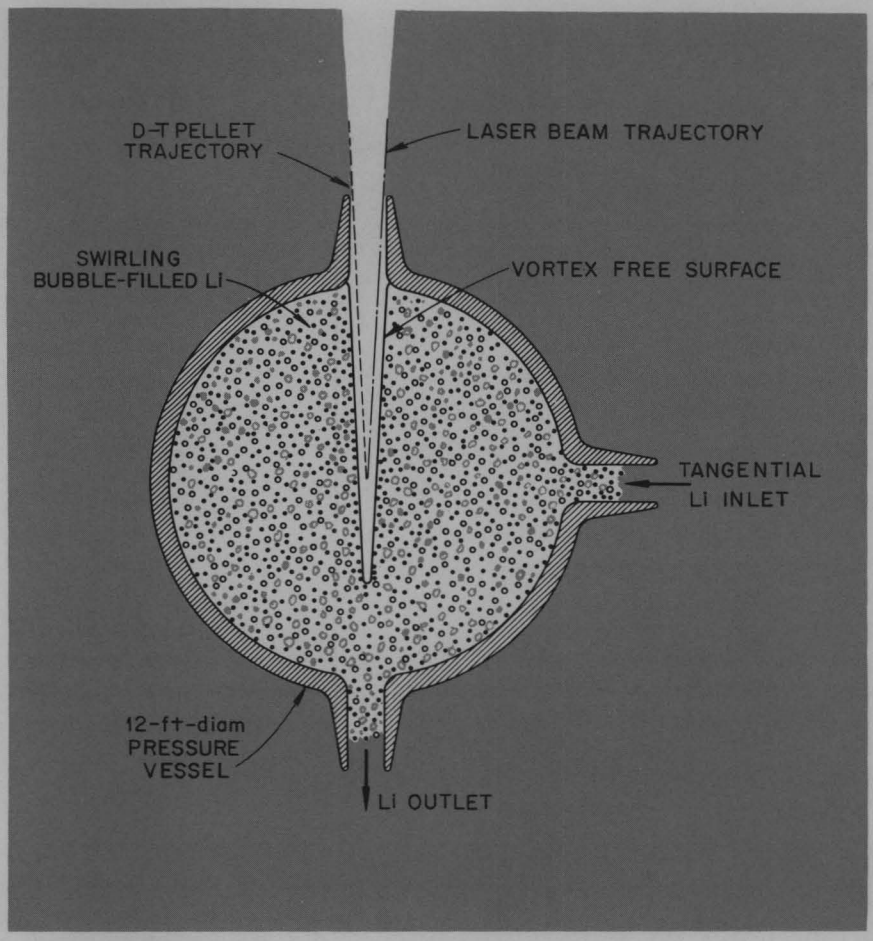
These substantial advances in injection capabilities will be applicable to many more experiments and should improve the plasma parameters to levels much nearer fusion levels.

Betty Maskewitz, mathematician


SOURCE MAGNET SUPPLY 0-3 A
FILAMENT SUPPLY 0-30 A
ARC SUPPLY 0-50 A 0-300 V
SOURCE COIL
1000 Ω
INTERMEDIATE ELECTRODE
ANODE
1000 Ω
AUXILIARY COIL
TARGET CATHODE
0-100 kV 0-3 A
48 — 0.5-cm-diam APERTURES ACCEL-DECEL ELECTRODES
0-25 kV 0-0.5 A
FIELD REVERSAL
LENS COIL
0 1 2 3 4 5
INCHES
TARGET
inches
gauss
10
10^2
10^3
10^4

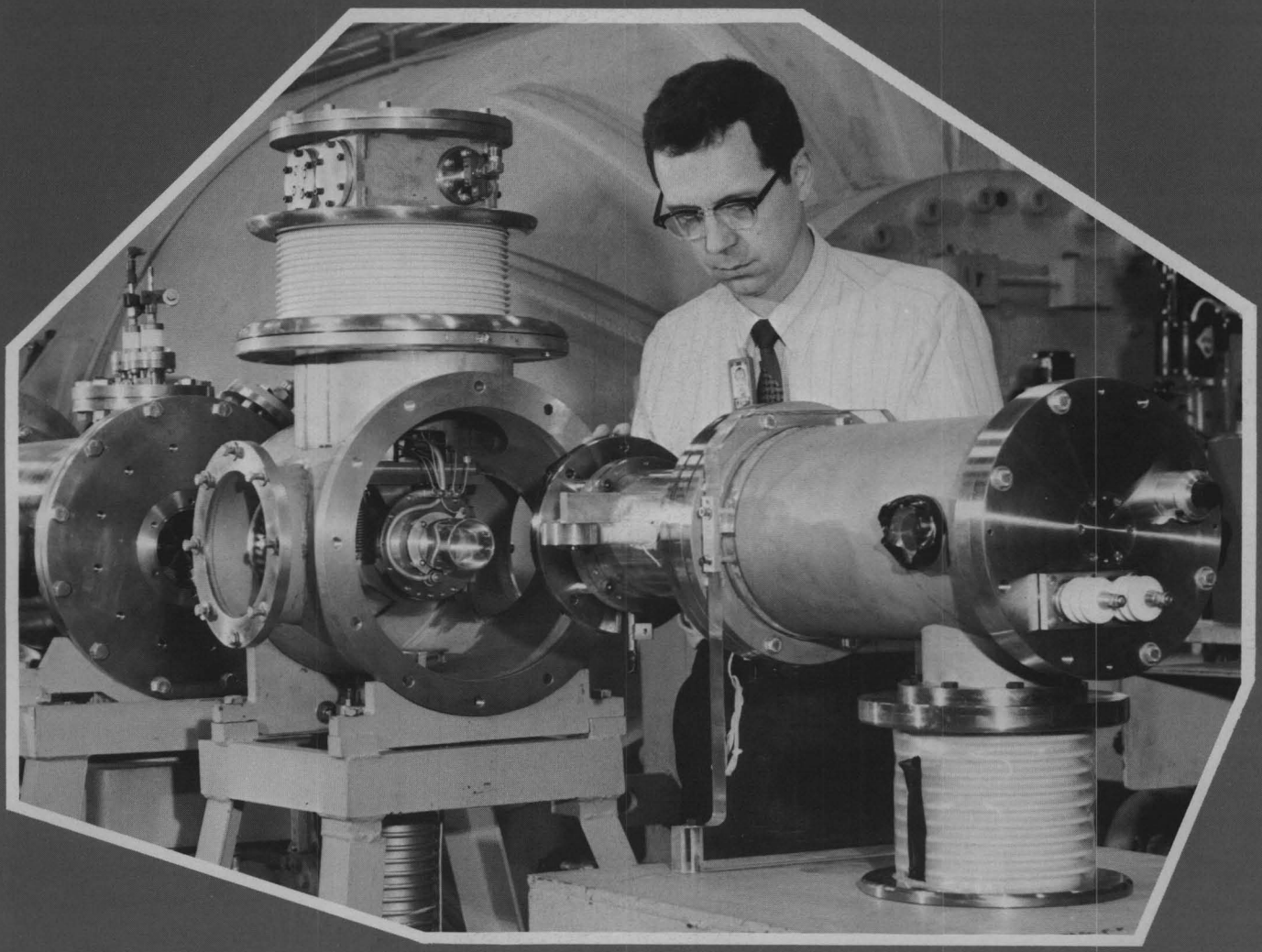
The ion source shown schematically on page 26 is capable of delivering 2 A of particles at energies of 30,000 V into a plasma confinement region. This source is particularly suited for heating existing Tokamak discharges to high ion temperatures and will be incorporated into the ORMAK experiment during the next year. To create the high current at these energies an intense arc is struck at the source region near the top of the drawing. The particles drifting from this intense arc impinge in the region of the auxiliary coils onto a three-electrode structure and form a plasma surface in this region. It is in the design of this region that the advances have been made. Through the proper placement and shape of holes within this region plasmas can be extracted and formed into a beam which can then be focused by a magnetic field which acts as a lens (shown at the bottom of the picture). In the case shown here, the beam is directed onto a target where its parameters are measured. This ion source, when the particles are converted into neutrals (the gas cell in that case replaces the target), is ideally suited to the heating of particles in closed geometries, such as the Tokamak discharge. Through modifications that can be made in the three-electrode region which shape the surface from which the ions are extracted, this source can be made suitable for use in open-ended confinement devices to create plasmas of high densities and high temperatures. These techniques are being carried out on the IMP mirror device at the Laboratory.

Liane Russell, geneticist



FUSION BY LASER *A new concept evolved during this past year by investigators at the Oak Ridge National Laboratory envisioned controlled thermonuclear reactions taking place through the interactions of laser light with deuterium-tritium ice pellets of small sizes. They found that it is possible theoretically to extract useful energy from these pellets when the laser light is converted into particle energy. The containment of the reaction products as plasma created by such an illumination expands rapidly, and the shock wave that occurs as this plasma grows would be contained within a spherical reactor vessel that makes use of present heavy steel technology and of the molten metal technology developed in the AEC reactor program. Reactors of fairly small sizes (up to 100 MW) and of low costs for the boilers of such reactors seem very reasonable. This schematic shows the boiler region of such a reactor complex. The lithium that has been heated through the interaction of these particles with the contained lithium goes into a heat exchanger where it is converted into steam to create electrical energy. The evolution of this concept will depend upon the development of suitably shaped and intense laser pulses of high efficiency.*

RESEARCH AND DEVELOPMENT



Physics

Audrey Best, biologist

Prediction of Superheavy Elements

It is almost 40 years since the first "atom smashers" ushered in the era of artificially made isotopes and new elements. Bit by bit, the periodic table has been extended from the heaviest known naturally occurring element, uranium (Z = 92), to element 104. However, these transuranium elements are found to be progressively more unstable as the number of protons in the nucleus increases, with the heaviest ones having half-lives measured mostly in seconds. Thus it comes as a source of excitement that an "island of nuclear stability" has been predicted for very much heavier nuclei, with half-lives of up to many years.

The search for these superheavy nuclei has caught the imagination of the nuclear physics community, stimulating intense activity by both theorists and experimentalists. The greatest interest centers around nuclei with the magic number of 184 neutrons and $Z \sim 114$ — a magic number predicted for protons. If such a superheavy nucleus is found, it will represent a rare instance in nuclear physics of a theoretical prediction preceding an experimental finding.

Basic to the prediction of these relatively stable superheavy nuclei is an understanding of the influence of shell structure on the properties of nuclear matter. For example, a generalized shell effect can account for the existence of quasi-stable, highly deformed shapes in fissionable nuclei called shape isomers. It was pointed out by an ORNL theorist that the positions of shells for a real nucleus are only slightly modified from those in a simple harmonic oscillator. Thus, a simple rule connecting shells and shapes is approximately valid: the most stable shapes of dynamically deforming nuclei occur when the reciprocal lengths of the nuclear axes are related to each other by simple integers.

Theoretical work at Oak Ridge over the last few years has been concerned with the stability of superheavy nuclei, their behavior as they undergo fission, and reaction mechanisms for their production. The production of superheavy nuclei in the laboratory will almost certainly use the bombardment of heavy nuclei with heavy ions (H.I.). Possible reactions are the (H.I.,xn) reaction, in which neutrons are evaporated from the compound nucleus, and the (H.I.,fission) reaction, in which the product nucleus fissions. Theoretical studies of these mechanisms have involved calculations of the dynamics of distortion of two spherical nuclei in head-on collisions. The most important effect was found to be the development of a neck as the nuclei approach each other and start to coalesce. Thus the energy for coalescence is raised only slightly by the Coulombic distortion. This result is important for choosing the maximum energy for heavy ion accelerators needed to explore the superheavy region.

The expectation that a superheavy nucleus will have $\bar{\nu} \simeq 10$ motivated the design of this multineutron detector by members of the Physics and Chemistry Divisions. It has been in use in a search for naturally occurring superheavy elements in samples of ore, minerals, manganese nodules from the ocean floor, extraterrestrial materials, and, recently, beam stops from high-energy (GeV) accelerators.

The detector consists of an array of 20 high-pressure helium-3 proportional counters, embedded in a cylindrical paraffin moderator that surrounds a 20-liter sample chamber. For single neutrons, it has a detection efficiency of 30%. Its efficiency for detecting multiple coincidences reflects the probability of multiple neutron emission as well as the counting geometry. If $\bar{\nu} = 10$, its efficiency varies from 62% for a multiplicity of 3 or more coincidences to 5% for a multiplicity of 6 or more. It is very insensitive to gamma rays; background rates, in a well-shielded basement, are only a few counts per day. Shown at the instrument are, l. to r., R. L. Macklin, whose original concept formed the basis for its design, and Joseph Halperin and R. W. Stoughton, chemists who are using the counter to examine natural samples and accelerator targets for multiple-neutron fission events that could indicate the presence of superheavy elements.

Theoretical studies of the mechanism of fission have been made for superheavy nuclei and for actinide elements. The conclusion is that a nucleus undergoing fission usually elongates first, passing through one or more quasi-stable shapes; it then begins to develop a neck and finally passes through a constrictive stage to scission, during which little if any elongation takes place. This work and the studies of measured fission energies in the actinide region have enabled physicists to predict the fission properties of superheavy nuclei. For a hypothetical nucleus with an atomic weight of 296 and a Z of 112, they estimate a total fragment kinetic energy of ~220 MeV, a total fragment excitation energy of ~90 MeV, and a value of 10 ± 1.5 for $\bar{\nu}$, the average total number of neutrons emitted per fission.

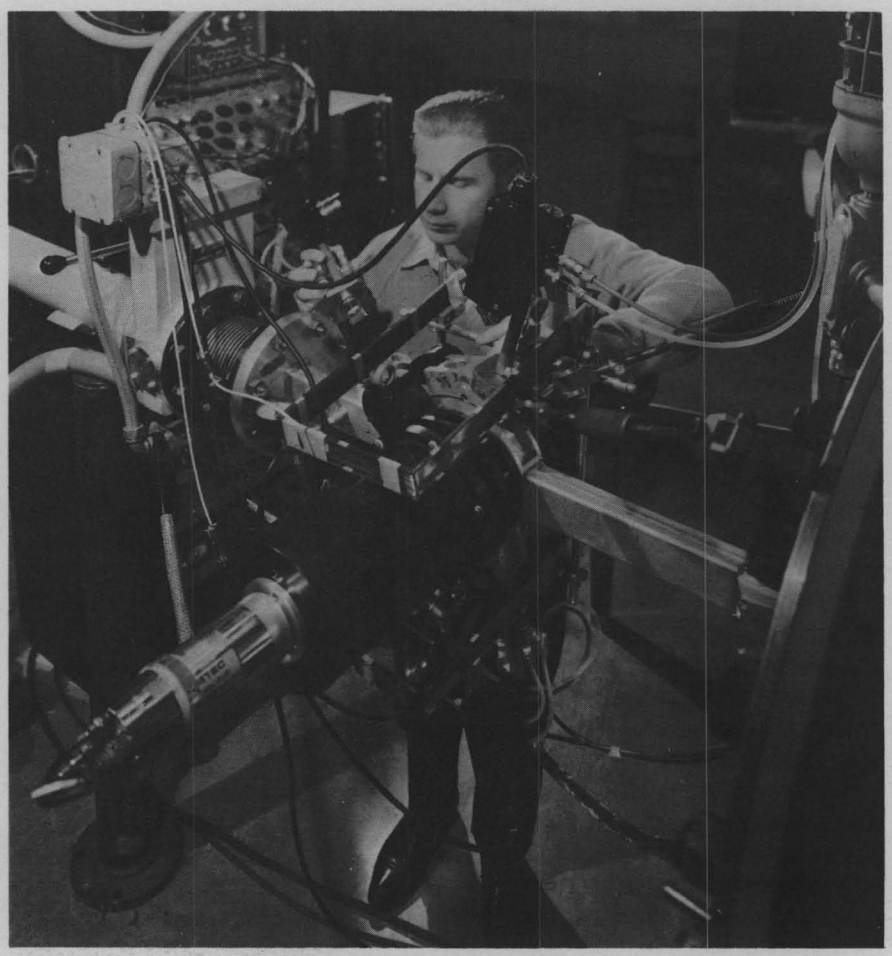
In the spontaneous fission of ^{252}Cf, an average total number of only 3.72 neutrons is emitted. If a value of $\bar{\nu}$ very much greater than this should be measured for a sample, it would be convincing evidence for the presence of a superheavy nucleus. Identification of the specific element could then be sought by other means — chemical isolation or measurements of characteristic x rays.

Rhoda Grell, geneticist

Fast-Neutron Capture

The neutron capture reaction, considered in the environment of a reactor core, implies a degree of finality which the other reactions do not possess. The capture of a neutron, with subsequent radiation of the neutron kinetic and binding energy in the form of gamma rays, spells an end to the participation of this neutron in the immediate neutron economy of the reactor. This unfortunate effect is tempered only slightly by two further possibilities: the neutron may be captured in a "breeder blanket," forming a fissionable nuclide; or the neutron capture may transmute a nuclide with a large capture cross section into one with a much smaller capture cross section. Including the reactor fuel, structural materials, moderators, reflectors, fission products, burnable poisons, etc., there are over a thousand isotopes that can perform the function of neutron capture in a reactor. The situation is further complicated by the design demands of contemporary fast (high neutron energy) breeder reactors. In these reactors most of the action is above neutron energies of some thousands of electron volts and may range up to 10 MeV. The measurement of the strong variation of capture cross sections with neutron energy, so critical to reactor design, then becomes an ambitious program.

Neutron capture cross sections are measured at the Oak Ridge Electron Linear Accelerator (ORELA) by detection of the gamma rays following neutron capture in a sample placed in a pulsed neutron beam. The capability of this installation for such measurements is unmatched. The high intensity, high resolution, and low backgrounds typical of this machine, and the large-capacity data acquisition computers permit measurements to be made with gram quantities of separated isotopes in relatively short periods of time. It becomes possible to essay the study of the systematics of neutron capture cross sections throughout the periodic table, as a function of the number of neutrons and protons in the target nuclide. In 1970, measurements were made of neutron capture in uranium, aluminum, fluorine, components of stainless steel, etc., that will be immediately and directly applicable to breeder reactor design. Measurements at ORELA are also pertinent to reactors not made by man. In this same neutron energy range, elements have been and are still being created in stars by neutron capture. This process of nucleosynthesis is described by theoretical models to which the neutron capture cross sections can be related.

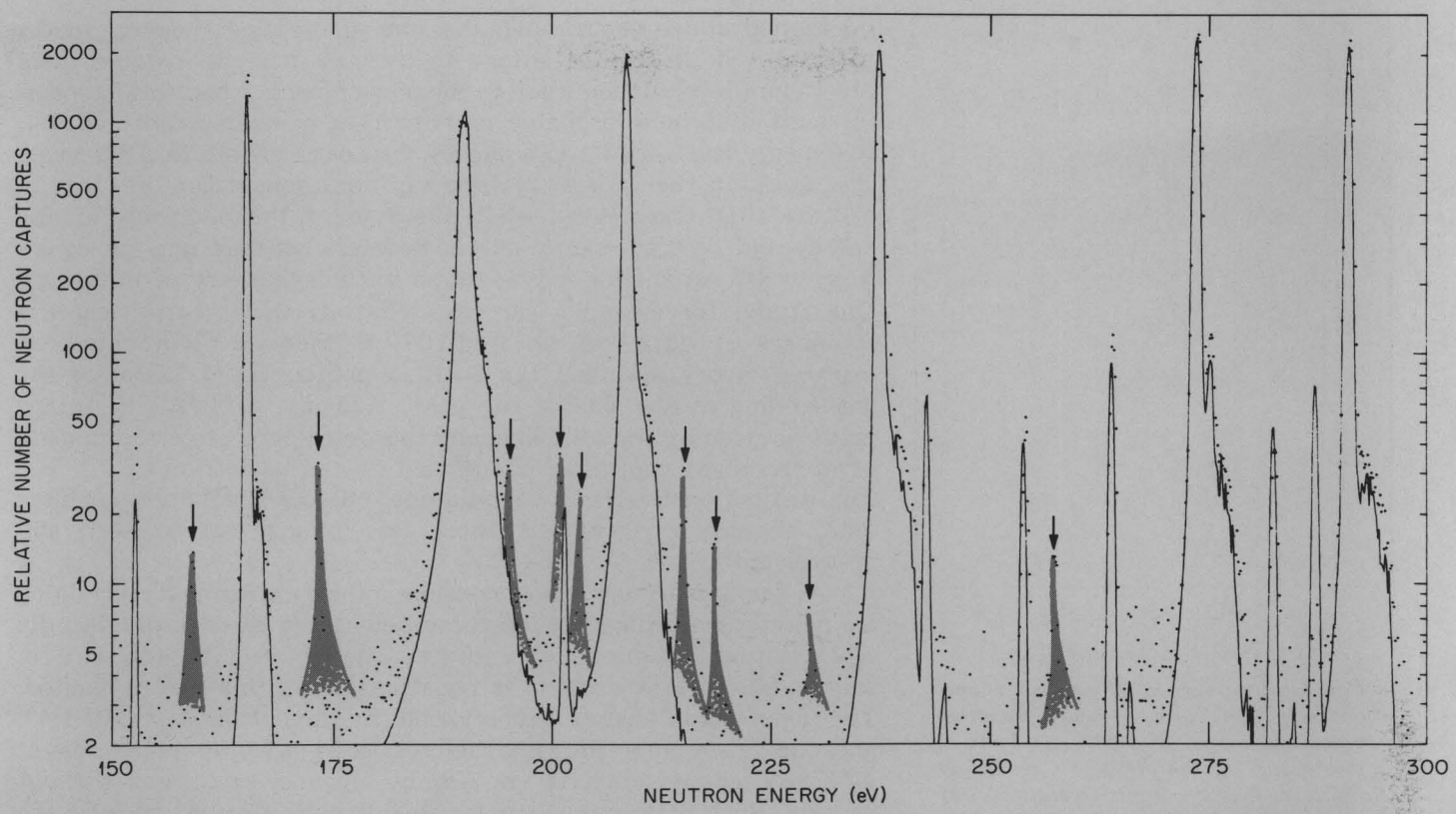


Barry Allen, visiting scientist from Australia, contemplates the neutron capture cross section measurement equipment at the 40-m flight station of ORELA. Liquid scintillators in the two large black cylinders detect gamma rays following neutron capture in the sample, which is placed in the pulsed neutron beam traveling from right to left in the picture. Four small samples can be inserted sequentially in the beam by air pressure without breaking vacuum. The electronic equipment in the background transmits to a computer memory numerical information based on the energy deposited in the detector and the relative time of the event to the billionth of a second.

Neutron capture is observed to occur predominantly at sharply defined peaks (resonances) on the neutron energy scale. According to theory there is also the possibility of capture occurring through a nonresonant mechanism which varies slowly with neutron energy. If this hypothesis is correct, competition between these two processes should be evident as interference at the 41,200-eV resonance in the target isotope of lead containing 207 neutrons and protons. High-resolution measurements made possible by ORELA show no interference at this resonance, and therefore negligible nonresonant capture. This same equipment can be used to make high-resolution measurements of neutron energy loss collisions ("inelastic" processes) and nuclear fission at high neutron energies.

The Electron Linear Accelerator

During 1970 ORELA was operated a total of 3700 hr for neutron time-of-flight cross-section measurements, accommodating as many as six experiments simultaneously on different flight paths. With its capability for producing neutrons at a peak rate of 4 billion billion per second and as many as 1000 2-nsec pulses per second, ORELA is expected to greatly increase and improve the body of



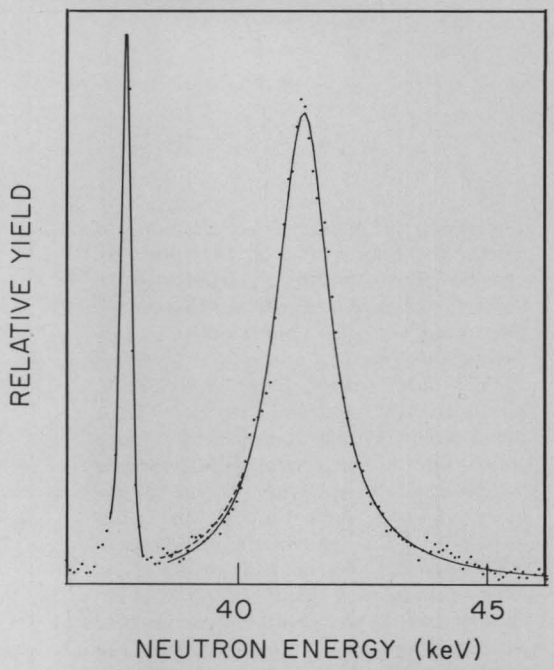
Capture of neutrons in a uranium-238 sample as a function of the incident neutron energy. In this figure the points represent data obtained in an Oak Ridge Electron Linear Accelerator experiment to determine the number of neutrons of various energies that are captured in a uranium-238 sample, and the smooth curve shows the same quantity calculated with uranium-238 capture cross sections from the Evaluated Nuclear Data File (ENDF/B data). The peaks correspond to neutron energies at which resonance absorption occurs, with the arrows pointing to resonances observed in the experiment but not included in the ENDF/B data. The increased number of resonances in the experimental data indicates that the probability for capture in uranium-238 is actually higher than would be predicted by the current set of ENDF/B cross sections. This information will be useful in optimizing the design of fast breeder reactors.

information on neutron-nuclei interactions for neutron energies as high as 10 MeV. The 1970 experiments, including both detailed studies of neutron reaction processes of interest to basic nuclear physics and specific cross-section measurements of concern to the liquid-metal fast breeder reactor program, represent a significant step in that direction.

Part of the ORELA contribution comes from a refinement of old data, and part comes from information of new kinds. A plot of the neutron capture cross section of uranium-238 as a function of neutron energy is an example of the former, and is, needless to say, information vital to the fast breeder, because it is through this process that the product plutonium-239 is to be made. Although the main peaks previously known to the breeder program are quite well reproduced by new ORELA data, nevertheless no fewer than nine minor peaks have been newly revealed in this energy range.

This work is, of course, being extended to other energy ranges. It is accompanied by a wide sweep (from 0.02 to 500,000 eV) of the cross sections for capture and fission in plutonium-239 — the other vital ingredient of the breeding process. These cross sections also pass through large peaks, and the relative probabilities of fission and capture vary from peak to peak. Furthermore, the number of neutrons emitted per fission may also vary from peak to peak, so this has to be measured at the same time. Altogether, ORELA will give the LMFBR program its best and most complete set of nuclear information basic to the essential processes.

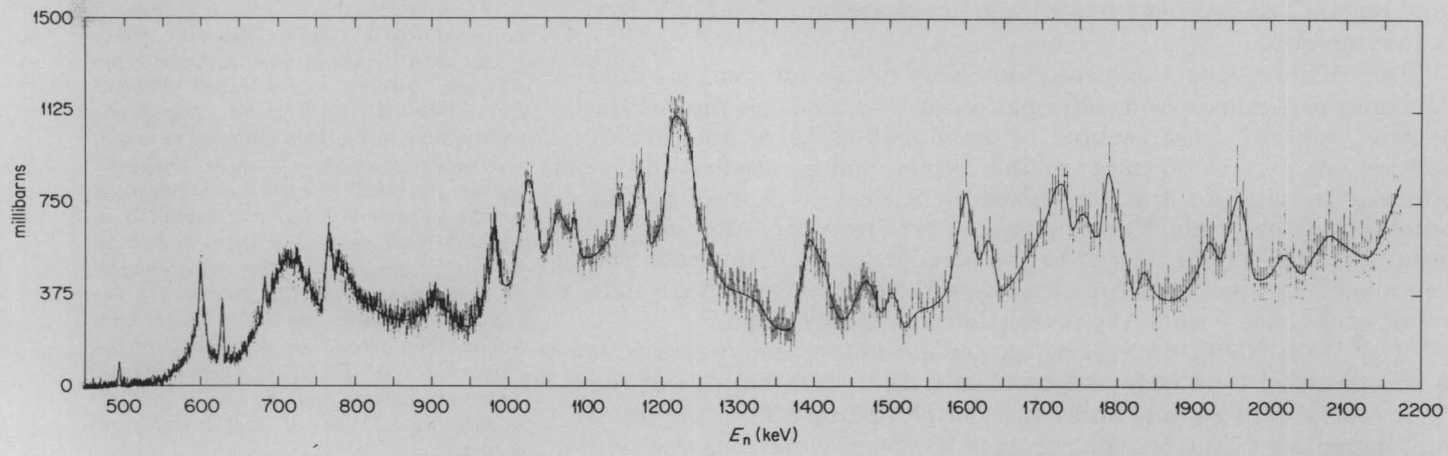
With data of such high quality, one can also check on fine points of nuclear physics in ways previously out of reach. The peaks



Neutron resonances of various shapes and sizes constitute the neutron capture cross section of lead-207. Analysis of the shape of the 41.2-keV resonance indicates that the nonresonance capture cross section between resonances (σ_{NR}) is exceedingly small, and readily explained in terms of current theories.

mentioned above occur when the sum of the kinetic energy of the neutron and its binding energy to the new nucleus matches quite precisely a level of excitation in the new nucleus. When this happens, interaction becomes probable, and often the neutron is captured. But the energy levels, and consequently the peaks, are erratically spaced. The question then arises: Is there any nonresonant capture, that is, capture that takes place when the sum of the neutron's kinetic energy and binding energy falls somewhere between nuclear excitation levels? An answer can be found in the symmetry of the peaks. One study, for example, shows a relatively wide neutron capture resonance at 41.2 keV in lead-207. If there is no nonresonant capture, theory says that the ORELA points should fall along the dashed line at the side of the peak. Actually, a "best fit" to the points is given by the solid line, and this corresponds to an admixture of nonresonant capture to the extent of a cross section of 0.1 mb. The distinction is clearly a subtle one, but ORELA is now yielding data of such quality that these fine points can be seen and appreciated.

As for data of new kinds, consider a third experiment, pertaining to inelastic scattering. A gamma-ray detector is set to respond to the de-excitation radiation of a known energy level at 440 keV in sodium-23, so that a count is registered when this level is excited. The fast-neutron energy is then varied (by time of flight in ORELA), and one gets a curve showing the cross section for an energy loss of 440 keV of neutrons in sodium by nuclear excitation without capture. Such data, important for shielding calculations because the process represents a transfer of energy from neutrons to gamma rays, here have been obtained for their relevance to the sodium-cooled LMFBR.

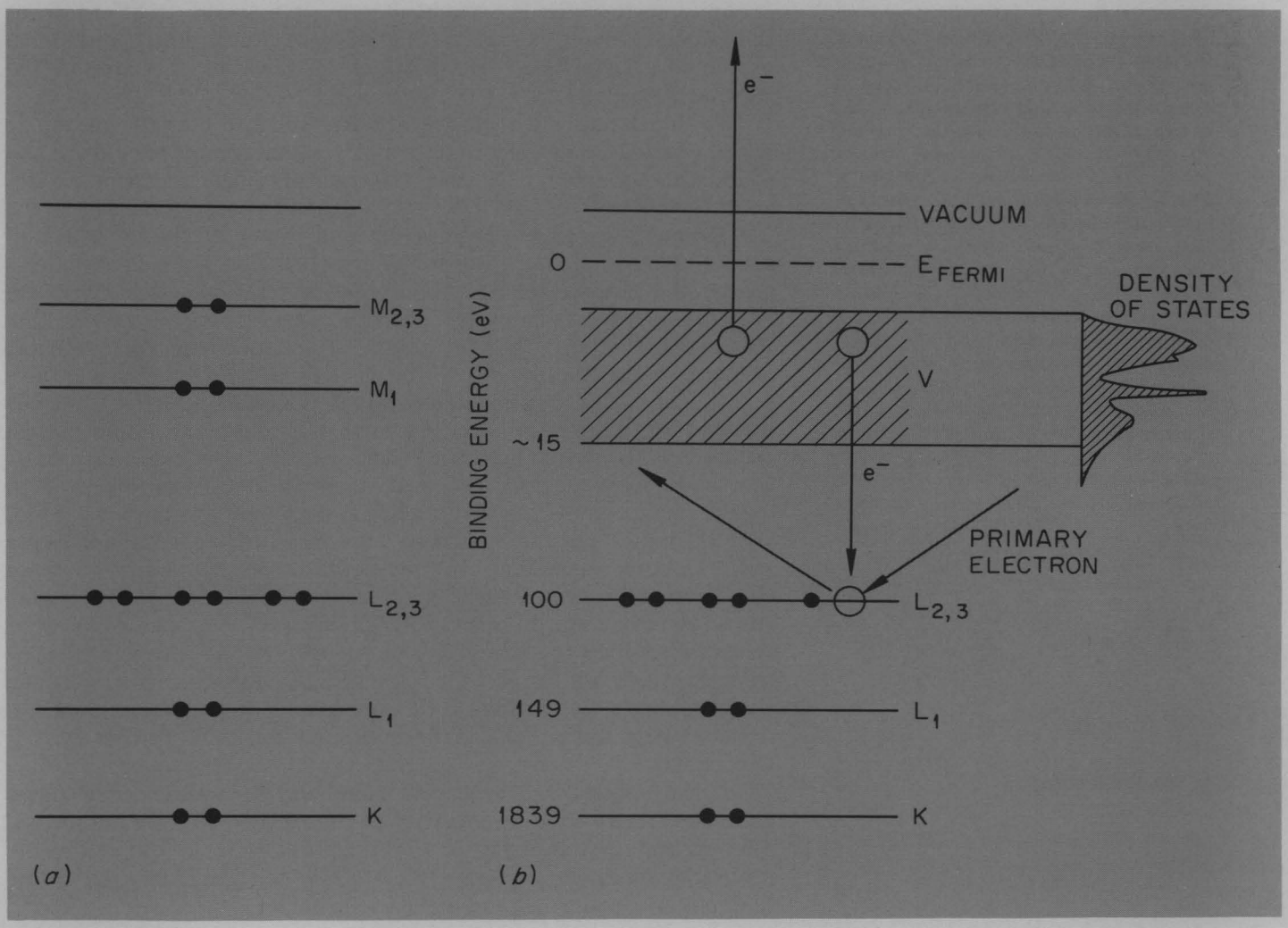


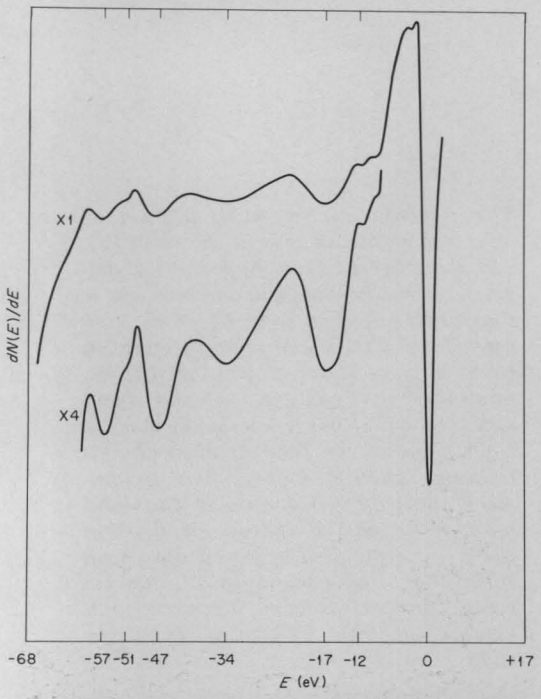
Cross sections for neutron inelastic scattering to the 0.440-MeV level in sodium-23. Since liquid sodium is being considered as the coolant material for fast breeder reactors, the behavior of reactor neutrons in sodium must be understood. The peaks in this curve of ORELA data indicate that neutrons at several energies in the 500-to-2200-keV range have a high probability of inelastically scattering with sodium nuclei.

Valence electrons, those in the outermost shells surrounding atomic nuclei, are responsible for many of the chemical and physical properties of matter. In isolated atoms — gases, for example — electrons in each of the shells are bound to the nucleus with discrete energies which are characteristic of the element. In solids the valence electrons exist as a rather diffuse cloud of nonuniform charge dispersed through a periodic array of nuclei. Moreover, the singular energy with which outer-shell electrons are bound to the nucleus in isolated atoms is, in a solid, broadened into a wide band in which valence electrons populate various energy levels within the band. The relative number of electrons at different energies within the band is termed the density of states.

Since energy levels of the electron shells are characteristic for each element, processes involving electrons can serve to identify material. For example, if an electron is removed from an inner level

The electron energy level diagram of silicon is shown as it is in the solid (b), *and the corresponding hypothetical diagram for the isolated silicon atom also is illustrated* (a). *The four electrons, two each from the M_1 and $M_{2,3}$ levels in each isolated atom, form the diffuse, nonuniformly charged valence band when many atoms coalesce to form a solid. The Auger process illustrated is initiated when a highly energetic primary electron from outside the solid knocks out one of the six electrons in the $L_{2,3}$ level. An electron drops down from the valence band to fill the vacancy, and at the same time a second valence electron is ejected from the solid.*



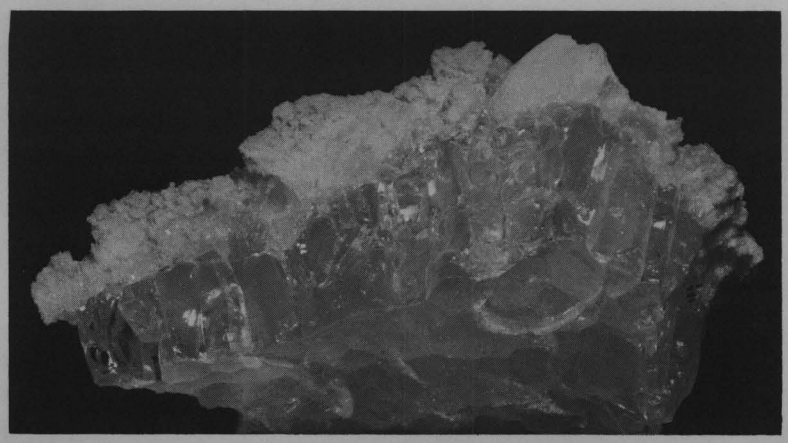


The silicon Auger spectrum is shown. Initially the ejected electrons have an energy of 92 eV, but for ease in illustrating discrete energy losses this energy is shown as zero on the scale and all other energies are relative to this value. Since the plasmon energies in silicon are well known, the events at —17 and —34 eV can be attributed to first- and second-order bulk plasmon losses by Auger electrons with an initial energy of 92 eV. Likewise, the —12 eV event can be attributed to the excitation of a surface plasmon, and the —6 eV portion of the spectrum arises from interband transitions excited by some of the Auger electrons. The electron transitions responsible for that portion of the spectrum near —50 eV most probably are different Auger processes involving electrons other than those discussed here.

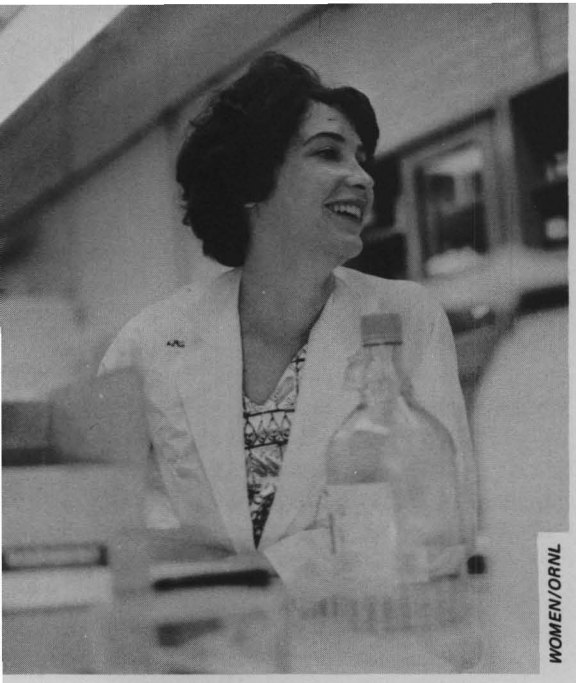
due to electron bombardment, etc., it can be replaced by an electron from a less tightly bound shell. At the same time, due to the excess energy within the atom, another electron is ejected. Such a sequence of events is called an Auger process after its discoverer, Pierre Auger. The ejected electron has a characteristic kinetic energy which is determined by the binding energies of the three electrons participating in the process. Should electrons from the valence band of a solid be involved, it is possible that the spectrum of kinetic energies of the emitted Auger electrons would reflect the density of states in the valence band. As an example, the Auger spectrum from silicon involving valence band electrons is approximately 60 eV wide, an energy spread which is considerably larger than the 15-eV width of the valence band, so that this experimental result cannot be explained on the basis of variations in densities of states in the valence band alone.

To understand such spectra it is necessary to consider means by which ejected Auger electrons could lose energy before exiting the solid. One possibility is that the ejected Auger electron excites another valence band electron to a different energy level within the band. Such excitations require discrete values of energy which in turn require that the Auger electron lose the equivalent kinetic energy and be detected at a fixed, lower energy. Another means for Auger electrons to undergo discrete energy losses is by exciting plasma oscillations in the cloud of valence electrons. Plasma oscillations are fluctuations in the electron density which occur with a frequency (energy) characteristic of the solid material. Previous work at the Laboratory has shown that in addition to bulk plasma oscillations, a surface electron plasma oscillation in the solid occurs at a lower frequency. Of course it is possible for Auger electrons to excite one or more plasma oscillations before escaping the solid. ORNL studies last year showed that most of the complex Auger spectra from solids can be rationalized on the basis of these characteristic energy losses experienced by initially monoenergetic Auger electrons due to excitation of plasma oscillations or interband transitions, since the characteristic energies in the spectrum related to such events are readily identified. No portion of such spectra can unambiguously be attributed to variations in valence band densities of state. Why this should be the case is not clear, and further work is in progress.

Auger spectra are useful in characterizing ultraclean surfaces because of the extreme sensitivity of the method to trace impurities. The general method also is useful in determining the electronic properties of solids, particularly metals, which ultimately determine their electric, magnetic, and dielectric behavior.



GROWTH OF MAGNESIUM OXIDE CRYSTALS *High-purity, optically clear single crystals of MgO and CaO are grown in the ORNL Solid State Division by the electric arc fusion method. The shorting graphite electrode is shown being removed by M. M. Abraham, thereby initiating an arc whose temperature exceeds 4000°C. The resulting crystal is shown in the inset.*



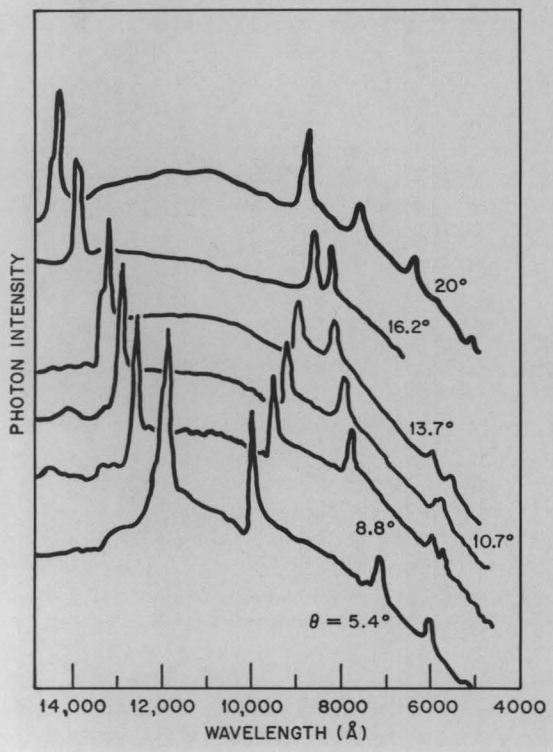
Winnie Palmer, biologist

Diffraction Grating Anomalies

In 1902 the famous optical physicist R. W. Wood was astonished to see bright streaks on a grating he illuminated with ordinary light. He termed them grating anomalies because they could not be explained by the ordinary grating theory of that time. These anomalies are rapid variations in the intensity of diffracted light that occur over a fairly narrow wavelength region when the incident light is polarized with its electric vector parallel to the plane of incidence, which in turn is perpendicular to the rulings on the grating. For a source with a continuous, slowly varying spectrum these anomalies appear as sharp peaks or dips in the diffracted spectra. Although these peculiar peaks have been studied both theoretically and experimentally ever since, it has only been in the past year that work done at ORNL has contributed to an understanding of their origin.

Interest in grating anomalies has revived for two primary reasons. One is the increasing use of concave gratings in monochromators, principally because of their ability to disperse and focus light over a large spectral region, including the vacuum ultraviolet, a region that has become important in space research and in solid-state physics. In experiments that require polarization of the light passing from the monochromator to the specimen, it is desirable to know something about these anomalous polarization effects and in many cases to modify or eliminate them.

A second reason for the interest in grating anomalies is the current belief that they can be explained in terms of collective excitations of electrons in the surface of the metal-coated grating. A quantum mechanical description of the process can be given in terms of an interaction between the incident photon and the electrons in the grating material. This interaction produces a surface wave that travels along the grating surface and subsequently makes an encounter with the ridges composing the grating surface. When the distance between the ridges is an even multiple of the wavelength of the surface wave, a high probability for de-excitation, or reemission, occurs, and peaks are found in the emission spectra. The velocity of these surface waves, of course, is dependent upon the grating material. A study of these intensity patterns has allowed determination of certain properties of these waves, called surface plasmons, in various materials such as gold, silver, and aluminum. These studies have also proven very useful in evaluating the contamination which occurs on all optical surfaces, especially those in vacuum systems evacuated by diffusion pumps. Indeed, NASA has found that optical components such as mirrors and gratings that have been calibrated on earth in ordinary vacuum systems change their optical properties when exposed to the very high vacuum of space.



Anomalous polarization peaks in p-polarized spectra from a tungsten source for an aluminum-coated grating. Spectra are shown for various angles between source and detector.

Isospin Conservation

Within the limits of mirror symmetry (parity conservation) and time-reversal invariance, the force between two nucleons gives every appearance of being highly complex. The nuclear force has a complicated dependence on the distance between two nucleons, on their relative momentum, on their relative angular momentum, and on the orientation of their respective spin axes. If examined in sufficiently fine detail, even the mirror symmetry of the nuclear force can be seen to be violated, and it appears possible that there may also be a small violation of time-reversal invariance in this force. It is therefore curious, and a matter of great interest, that this force appears to be, to a large extent, insensitive or invariant to the electrical charge of the interacting nucleons. This property is referred to as the charge independence of nuclear forces.

This near-perfect charge independence of nuclear forces has led to the isospin formalism for the classification of nuclear states. In this theory the neutron and proton are the two possible quantum states of one heavy particle, the nucleon. After eliminating the effect of the charge on the proton, they have identical nuclear interactions with nuclear matter. One consequence of this formalism is that in nuclear reactions of the type

$$A + B \rightarrow C + C',$$

where C and C′ are members of the same isospin multiplet and where either A or B has isospin 0, the yields of C and C′ should be symmetric about 90° in the center-of-mass system. This prediction has been tested and checked in the reaction

$$^{4}He + {}^{10}B \rightarrow {}^{7}Be + {}^{7}Li \qquad (1)$$

and in the reaction

$$^{14}N + {}^{12}C \rightarrow {}^{13}C + {}^{13}N. \qquad (2)$$

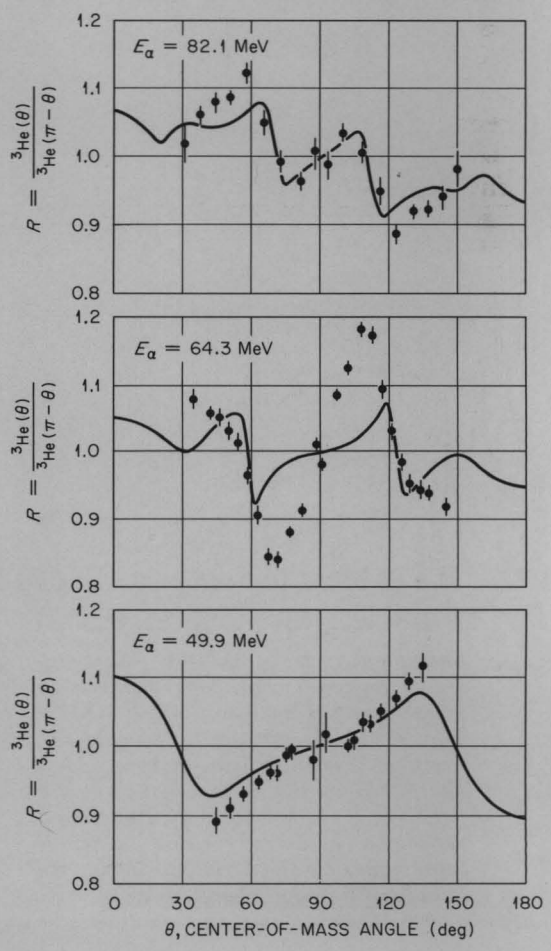
Recently the test has been extended at the Oak Ridge Isochronous Cyclotron Laboratory to the reaction

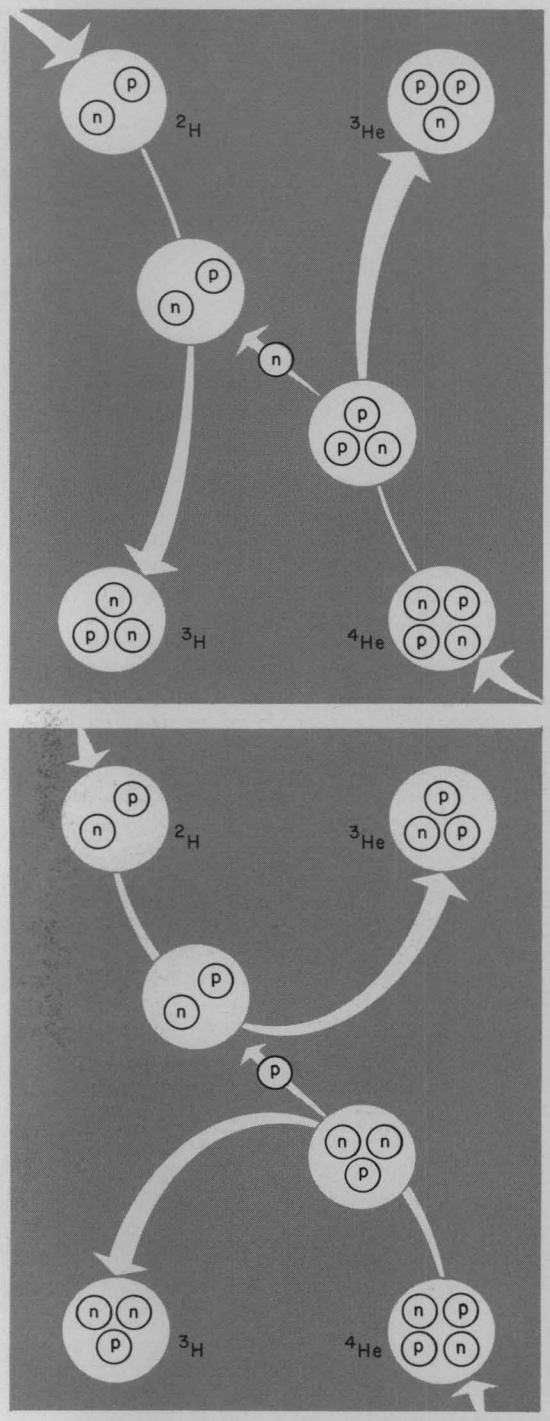
$$^{4}He + {}^{2}H \rightarrow {}^{3}He + {}^{3}H \qquad (3)$$

with surprising results. Measurements of the yields of one of the reaction products, ^{3}He, were made at an angle θ and simultaneously at the supplementary angle $180° - \theta$. These angles are symmetrically located with respect to 90°, and the isospin formalism predicts the ratio of the observed yields to be identically unity for all choices of the two symmetric angles. However, there were seen to be deviations as large as 15 to 20% from unity, and evidently the isospin concept was breaking down in this case. The reaction was examined at three different bombarding energies to check the validity and consistency of the results. In each case significant deviations from the required symmetry were observed.

A possible source for this apparent violation of charge independence is the presence of Coulomb fields, which, of course, are

Experimental results and theoretical predictions for the isospin conservation experiment $^{4}He + {}^{2}H \rightarrow {}^{3}He + {}^{3}H$ at the three bombarding energies studied. The experimental points are the observed asymmetry in the yield of helium-3 at a center-of-mass angle θ and the supplementary angle $180° - \theta$. The concept of isospin conservation leads to the prediction of a value of $R = 1.0$ at all center-of-mass angles. The theoretical curve results from a calculation based on the assumption that the reaction proceeds via a direct, single-neutron and single proton, transfer process.





Illustrated concept of the two competing processes, both of which can be taking place in the reaction $^4He + {}^2H \rightarrow {}^3He + {}^3H$. In the upper drawing the transferred particle is a neutron and is unaffected by the presence of Coulomb fields. In the other case, the transferred particle is a charged proton, which is acted upon by the Coulomb fields produced by the other charges present.

dependent on the charge state of nucleons and nuclei. In simplest terms, the reaction studied can take place by a combination of two distinct but, in this case, indistinguishable processes. The initial deuteron can capture a neutron from helium-4 to become a hydrogen-3 nucleus and leave a residual helium-3 nucleus, or the deuteron can capture a proton from helium-4 to become a helium-3 nucleus and leave a triton (hydrogen-3). A theoretical calculation based on this simple picture can evidently account, in a qualitative way, for the observed asymmetry. The theory reproduces the general trends of the experimental data but falls short of giving the correct magnitude. However, before a definite conclusion about the validity of isospin conservation can be drawn from these experiments a more detailed calculation will be required.

The Moon and Batavia

For several years there has been in the Neutron Physics Division of the Oak Ridge National Laboratory a program, supported by both the U.S. Atomic Energy Commission and the National Aeronautics and Space Administration, to develop methods for calculating the penetration of very high energy nucleons and mesons through matter. An excellent example of the overlap of the interests of these agencies in this area occurred during the last year when a computer code developed as part of the program was used in similar but quite distinct applications for the two agencies.

When high-energy particles pass through matter, some of the nuclei in the matter become radioactive as a result of nuclear interactions. In particular, the soil shields in the vicinity of very high energy accelerators will become radioactive through this mechanism. The amount of this activity that will be produced is of concern because some of the radioactive nuclei may be carried off the accelerator site by underground water. Calculations of the radioactivity around the accelerator under construction at the National Accelerator Laboratory at Batavia, Illinois, have been made, and as a result the design group at NAL has been able to show that rather small amounts of the activity will leave the accelerator site.

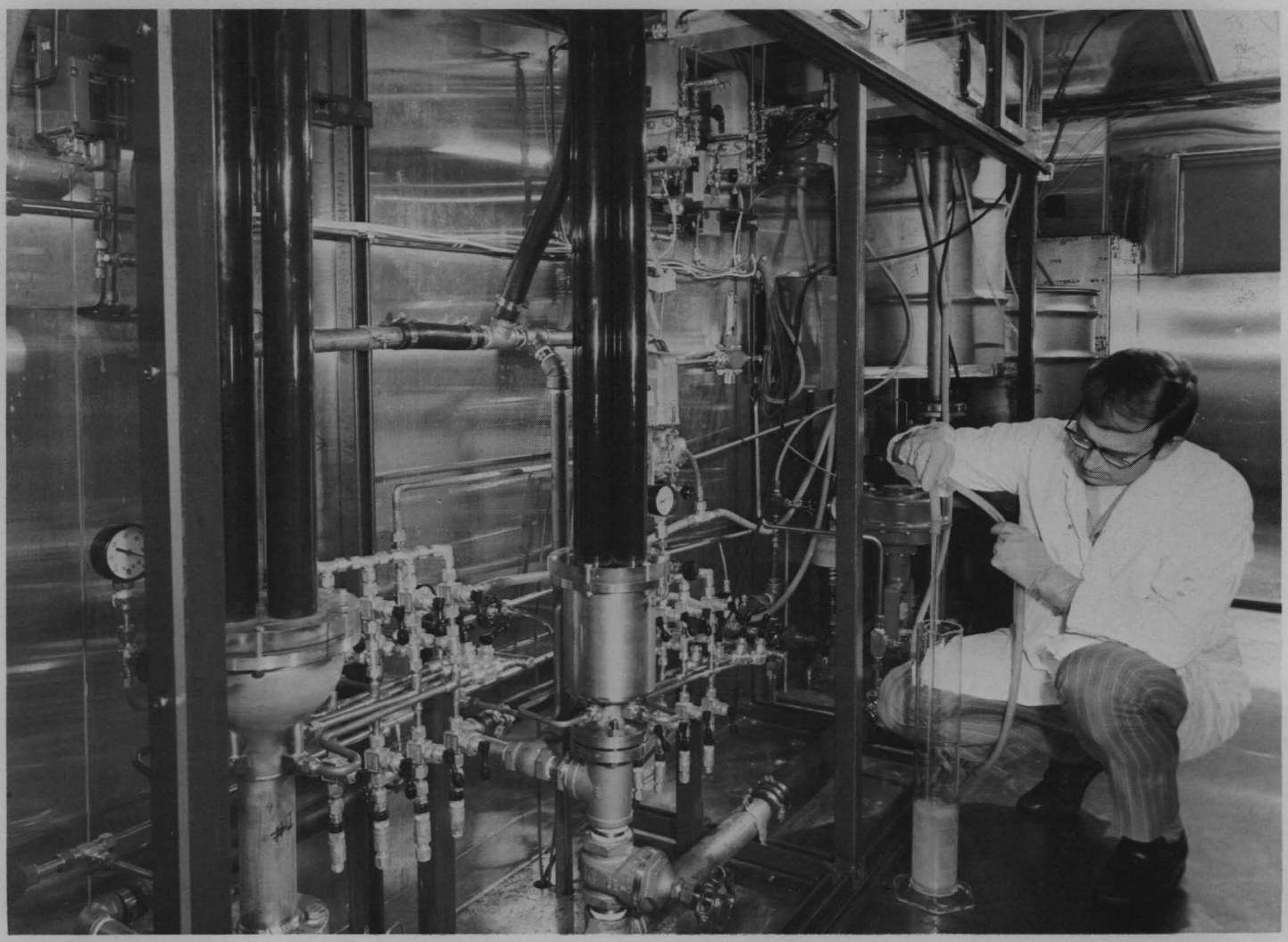
Another example of the effect on matter of high-energy particles is the activity induced in the moon by galactic and solar cosmic rays. Experimental data on the kind and amount of this radioactivity have been obtained from the rock samples returned to earth by Apollo 11 and 12. Calculated results of the activity to be expected in the moon have been obtained and found to agree well with the experimental data. In order to carry out the calculations, it was necessary to make assumptions about the history of cosmic-ray bombardment of the moon, and the agreement obtained between the experimental and calculated results tends to confirm these assumptions. In addition to the activity, the calculations provide much information that is not available experimentally and that will aid in the planning and interpretation of future Apollo measurements. For example, the calculations have provided an estimate of the energy spectrum of photons escaping from the moon's surface which is of considerable interest, since this spectrum will be measured during subsequent Apollo flights.

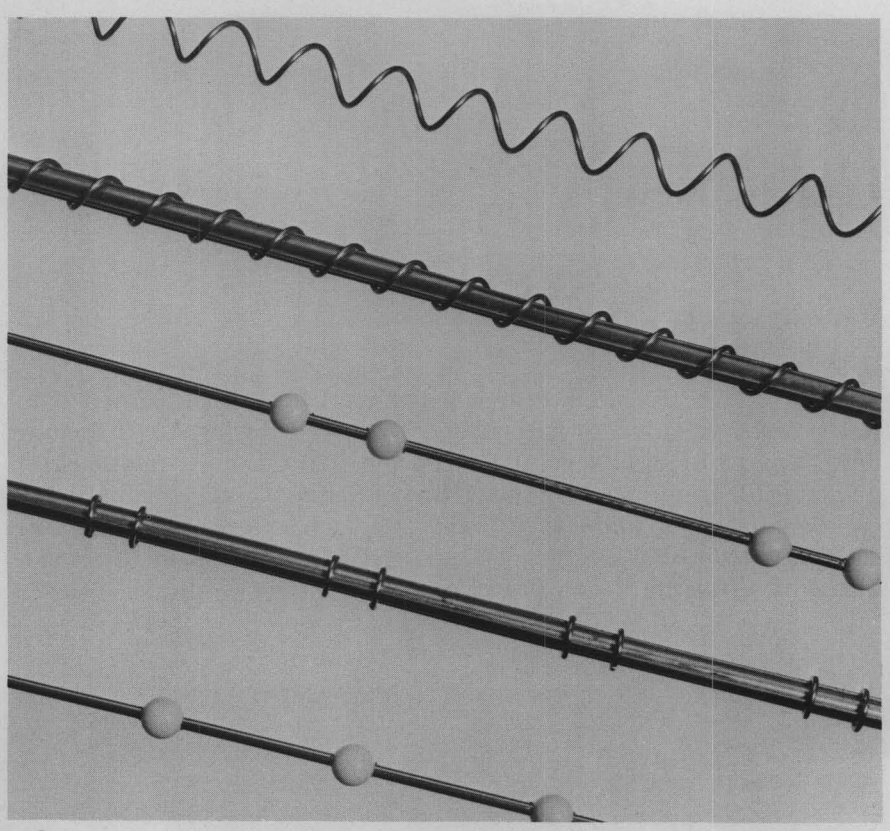
Chemistry

Water Research

The Water Research Program at Oak Ridge is concerned with many areas of aqueous processing. Examples during 1970 include development of dynamically formed hyperfiltration membranes for desalination (supported by the Office of Saline Water); electrochemical techniques for removal of toxic ions, such as mercury, copper, or cadmium (National Science Foundation); hyperfiltration for treatment of effluents from the dyeing of textiles (National Science

Parts of the mobile hyperfiltration unit. The dark liquid inside the vertical transparent jackets at left and center is primary effluent, after treatment with iron(III) and carbon. It is being pumped past the filtering surface, mounted on a tube, in the center of the jacket. The product stream, being collected by Warren Sisson, is clear, though air bubbles make the liquid in the receiver look slightly turbid.





Turbulence promoters used in hyperfiltration work come in all shapes and sizes.

Foundation); and influence of hydrodynamics on hyperfiltration of sewage with cellulose acetate membranes (Water Quality Office of the Environmental Protection Agency).

Recently, our interest in filtration has expanded beyond hyperfiltration of low-molecular-weight solutes to include low-pressure removal of particulates and ultrafiltration of colloids. By maintaining a flow of the solution being treated past the filtering surface, buildup of a thick cake of filtered material is retarded. However, for high production rates with typical polluted waters, it appears also necessary to prevent constituents from forming tight layers on the surface, similar to dynamic membranes deliberately formed for hyperfiltration.

We have found cross-flow filtration to have potential for a number of applications but have focused heaviest attention on effluents from primary treatment (settling) of municipal sewage, on a program funded by WQO-EPA. Laboratory experiments and recently on-site tests, carried out in a mobile unit at the Oak Ridge East Waste Treatment Plant, have been under way for about a year. The primary effluent is first treated with a coagulant, usually a ferric salt, and adsorptive carbon. It is then pumped under low pressure, typically 30 to 50 psig, past a filtering surface, for example, a fine-mesh screen or a fire hose jacket. The filtered product has a turbidity about equal to that of Oak Ridge tap water. The organic carbon content is reduced about as much as projected for combinations of conventional secondary and tertiary treatments. Further, as a consequence of the coagulant treatment, usually more than 99% of the phosphate is removed.

The process should be at least a technically superior alternative to conventional sewage treatment. A plant designed for a given volume would require only a small fraction of the space needed for biochemical treatments. In contrast to hyperfiltration, dissolved salts would not be substantially reduced, except for adsorbed ions, such as phosphate; the product should, however, be good enough for reuse in some applications, and with dilution and chlorination, perhaps even as drinking water.

We are not far enough along to make an accurate projection of costs. Under some conditions, production rates have been several hundred gallons per square foot per day. Favorable and economic combinations of filter surfaces, pressures, circulation velocity, chemical treatment, and backwashing intervals have not, however, been established. We are optimistic that costs of treatment will be acceptable, in view of the quality of the product.

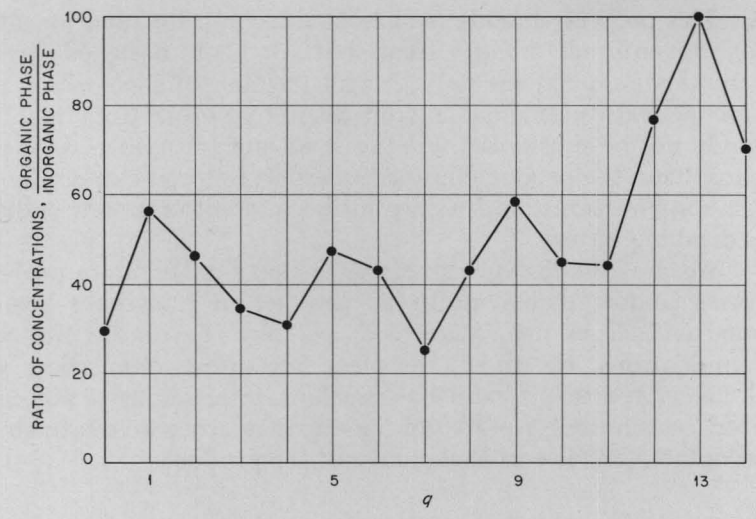
Rowena Chester, physicist

The Tetrad Effect

In the periodic table, there are two groups of elements that do not fit into the regular, cyclic variation of chemical properties with increasing atomic number. These are, of course, the lanthanides and the actinides. The former, classically known as the rare earths, extend from lanthanum ($Z = 57$) to lutetium ($Z = 71$), and the latter extend from actinium ($Z = 89$) to lawrencium ($Z = 103$). Each series, accordingly, contains 15 elements. All students of atomic structure know as one goes from one lanthanide or actinide element to the next higher, the electron that has to be added does not attach itself to the surface of the atom, but instead goes into a subsurface shell (the $4f$ shells in the case of the lanthanides and the $5f$ for the actinides). The chemical differences between the individual lanthanides and between the individual actinides are accordingly normally much more subtle than they are between adjacent elements of the main part of the periodic table, where each new electron attaches itself to the outside of the atom, with a consequent major effect upon the atom's chemical properties.

Recently a secondary periodicity has appeared within the lanthanide and the actinide series, and since it is a periodicity in groups of four, it has become known as the tetrad effect. It has evidenced itself in various ways, and the attached sketch shows an example. Here the equilibrium concentrations are plotted when the successive lanthanide(III) ions are dissolved in two immiscible liquids that are in contact. (The liquids are actually benzene with an organic complexing agent, and water containing lithium bromide and hydrogen bromide. Since the III ions are used, the outer-shell electrons of the normal atoms are missing, and the $4f$ electrons consequently have a greater chemical effect.) The symmetrical groups of four are evident in the figure, although one has to use the central point twice.

What is the atomic origin of the tetrad effect? Chemistry Division research last year called attention to a correlation with the quantum numbers of the lanthanide(III) and actinide(III) ions. If you list the ground-state total electron spin and total orbital angular momentum



Example of the Tetrad effect. Variation of ratio of concentrations (organic phase to inorganic phase) with q for lanthanides (III).

quantum numbers for all of the electrons in the *f* shells in the two series, you get a table like this:

Number of electrons in the *f* shell	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lanthanide III ion	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Actinide III ion	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
2 × total electron spin quantum number	0	1	2	3	4	5	6	7	6	5	4	3	2	1	0
Total orbital angular momentum quantum number	0	3	5	6	6	5	3	0	3	5	6	6	5	3	0

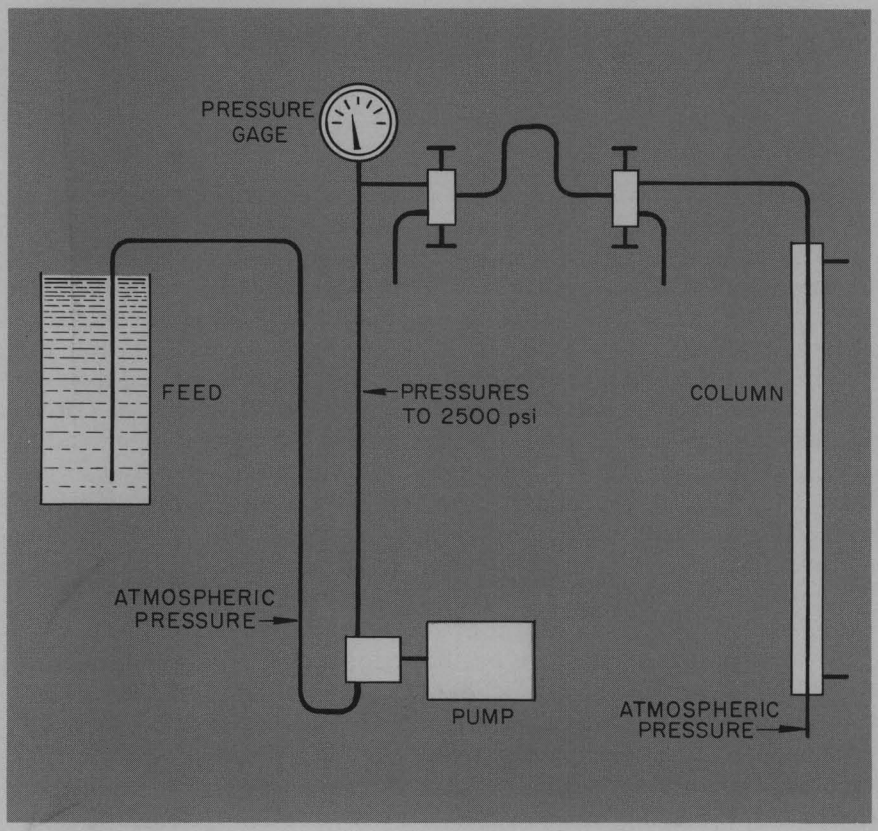
Inspection of the table shows two symmetries. One is a right-left symmetry about gadolinium and curium which divides each series into two halves; it is a consequence of a familiar spectroscopic rule which, when applied to the case of 14 available electron spaces, states that a configuration of (for example) 4 electrons and 10 holes (promethium or neptunium) behaves like a configuration with 10 electrons and 4 holes (holmium and einstenium). The second divides each of the above halves into quarters; it is in the bottom line and shows groupings of four when combined with the first symmetry, provided you use the central place twice.

Striking as this correlation is, it does not say much about fundamental causes, nor does it say much about such matters as relative solubilities in benzene and water. To understand the matter more fully, the study followed the trail a little farther to find tetrad variations when the changes in interelectron Coulomb repulsions are calculated, as the 14 electrons are successively added into an *f* shell. The tetrad variations are also correlated with variations in the lanthanide(III) and actinide(III) ionic radii. Both of these effects can modify the energies of the complexes that the lanthanides and actinides may make with other substances, and indeed the latest quantitative estimates indicate that they are most likely the mechanisms for the tetrad effect. In any case, the tetrad effect is an example of the mixture of atomic physics and classical chemistry that is one of the hallmarks of modern basic chemistry.

Advances in High-Pressure Ion Exchange

The development of pressurized ion exchange at ORNL several years ago has led to the solution of some difficult separations problems, with substantial savings in time and money. This method differs from conventional ion exchange by using much smaller resin particles (10 to 40 μ in diameter), necessitating a high-pressure pump to overcome the increased flow resistance of the finer particles. Ion exchange chromatography offers one of the best ways for separating elements such as lanthanides and actinides, which are generally quite difficult to isolate. The pressurized ion exchange technique offers certain advantages over conventional ion exchange, including improved resolution or quality of separation, a large reduction in the time required to achieve a given separation, and the ability to process extremely radioactive materials.

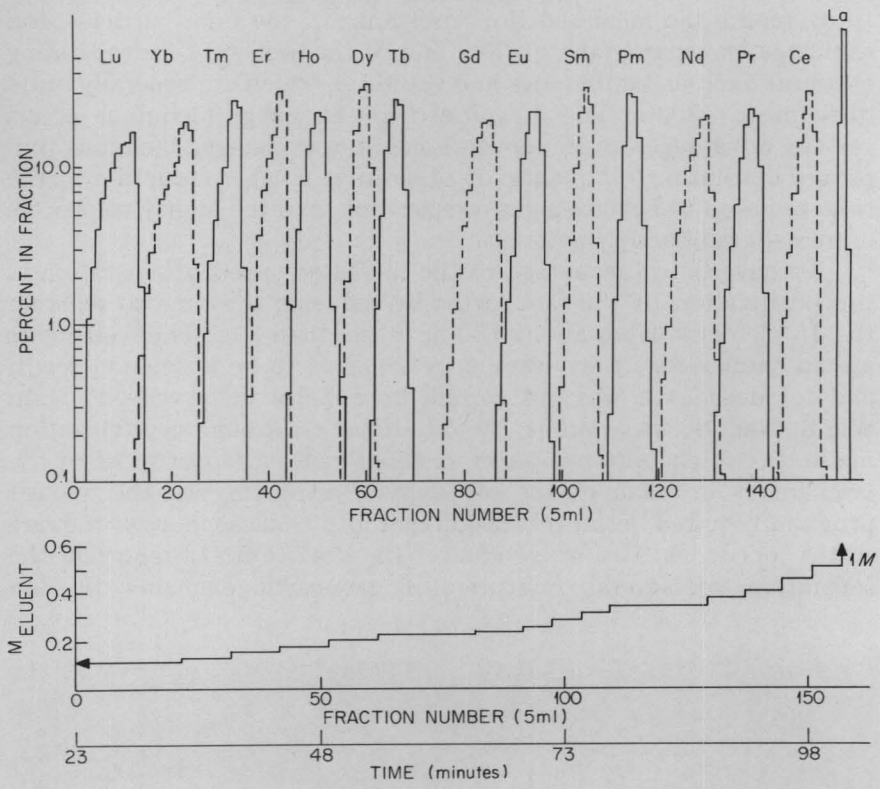
We have taken advantage of the increased speed of separation in the purification of the rare earths by reducing the time to separate the 15 elements from about 100 hr to less than 2 hr. These elements are so similar that they were once believed to be a single element, and for decades it was not certain how many there were. Prior to World War II, separations by laborious fractional crystallization methods, which required years, resulted in isolation of most of the lanthanides in a fair degree of purity. During the war the nuclear program required better separation methods because most of the rare earths occur as fission products. In 1947 ORNL reported the separation of several mixtures of rare-earth elements by ion



A positive displacement pump provides the pressure necessary to force solutions through the ion exchange column at the desired flow rate. The pressure drops to atmospheric along the length of the column, and only those components between the pump and the top of the column contain the high pressure. These components usually include a pressure gage and one or more valves, depending on the application.

Margaret Cone, biologist

The use of finely divided resin in a pressurized ion exchange system permits a much more rapid and complete separation of elements that are otherwise very difficult to separate. This is an elution curve for the simultaneous separation of all 15 rare-earth elements. The amount of each element except promethium was 5 mg; promethium was at tracer level. The resin column contained 22 ml of 25 to 50 μ Dowex 50W-X8 resin in a bed 33 cm long, and elution was done with an increasing concentration gradient of α-hydroxyisobutyrate. Each element is obtained in over 99% purity and yield.



exchange. This was a great improvement over previous methods, as several elements could be separated in about one week.

The precise determination of fission product rare earths remains important in nuclear research, and it has consumed considerable effort. The separation is still accomplished by ion exchange chromatography, very much as it was over 25 years ago; and the determination of all the rare-earth elements requires several days. In 1970 members of the Chemical Technology Division at ORNL applied the pressurized ion exchange method to this problem, and in a typical run, the 15 elements were quantitatively separated in less than 2 hr. Indeed, even further reduction in time could be achieved, were the human manipulations to be replaced by automated equipment. This method is now being used at another AEC laboratory for routine rare-earth analysis, and the time for a complete analysis is reduced from 100 hr to between 3 and 4 hr.

Pressurized ion exchange has been applied with complete success to production of the highly radioactive transcurium elements, and all the products, berkelium, californium, einsteinium, and fermium, are processed by this technique. When the heavy-element production program was initiated, with the goal of producing 1 g of californium per year and varying amounts of other heavy actinide elements, there

was uncertainty as to how the final purification of such intensely radioactive materials would be accomplished. The level of production has now permitted the processing of more than 60 mg of californium in a single run with a 100-ml resin column, and we see no limitation prohibiting scale-up to process hundreds of milligrams of californium in a single run. These extremely radioactive elements can be processed with excellent results using pressurized ion exchange, and we know of no alternate method we could use with confidence to accomplish this goal.

During these ion exchange processing operations in the Transuranium Processing Plant (TRU) the deposition rate of radioactive decay energy is greater, by factors of 10, than the radioactive power density encountered in reprocessing of nuclear power reactor fuel. Satisfactory operation is obtained even with alpha and fission fragment radiation exposures of several kilowatt-hours per liter of resin. A study has been initiated to determine the value of pressurized ion exchange for fuel reprocessing as well as other special applications.

WOMEN/ORNL

Mary Jane Cook, physicist

Mathematics

Shielding Calculations by Discrete Ordinates

One aspect of mathematics that has come into prominence during the past few years is the use of numerical transport theory methods for calculating the penetration of neutrons and gamma rays through material thicknesses as large as those used in reactor shields. Because the development of transport techniques for such "deep-penetration" calculations was itself a complicated and costly problem that obstinately resisted solution, the shields around reactors in operation today have all been designed by semiempirical methods that embody a significant amount of conservatism. As a

Frances Pleasonton, physicist

result, they are oversized and overly expensive — two characteristics that are increasingly intolerable as the use of nuclear power plants becomes widespread. The Laboratory's Neutron Physics Division has been working on improving shield design procedures for a number of years, with the efforts largely concentrated on adapting the Monte Carlo transport method (a stochastical method) to more precise shield calculations. In recent years equal attention has been given to a finite-difference technique known as the method of discrete ordinates. For work on this method, which was originally developed for criticality calculations for small highly enriched systems, the services of the Radiation Transport Methods Section of the Mathematics Division were enlisted in 1970.

The discrete-ordinates method is limited to one- and two-dimensional geometries but yields highly differential results for any system to which it is applicable. The system is divided into a large number of difference cells that are finite in space, angle, and particle energy, and the flux in each cell is calculated by successive interations. The enormous amount of computer storage needed for such a calculation, together with the tremendously large number of operations required, essentially precluded the application of the discrete-ordinates method to shield systems until the third-generation computers became available. Even then, a number of shortcomings inherent in the method itself necessitated further development for shield applications.

One obvious difficulty arose from the use of the "diamond-difference" technique, which assumes that the volume-averaged flux in a cell is the mean of the fluxes at opposing cell faces. For shielding problems, this assumption led to serious difficulties, since it becomes invalid in shield regions where steep flux gradients exist and the resulting cell-face flux in the direction of the calculational flow may have a negative value. This problem has been removed by using less accurate but more physically plausible integration techniques when negative fluxes occur in these shield regions. Another difficulty stemmed from the simplifying assumption that all particle scattering within the system is isotropic. This assumption is unrealistic for shields, in which the anisotropic scattering in the forward direction contributes most to the deep penetration. The angular dependence of particles transferring from one energy group to another is now approximated by a low-order Legendre series.

A third problem arose from the excessive computer times required for the iteration process due to scattering within an energy group, a problem that has been solved by supplementing the original Gaussian iteration techniques with convergence acceleration schemes. A fourth problem that occurs only in two-dimensional calculations is flux oscillations that correspond to finite directions. Called the "ray effect," this problem has been greatly reduced by the use of an analytic first-collision source. A related difficulty encountered in the calculation of radiation streaming through a slit in a missile silo shield was resolved by using a biased high-order quadrature that could accurately represent the streaming paths. This technique is

now finding wide application in complex shielding problems for fast breeder reactors.

The adaptation of the discrete-ordinates method to shielding will continue as the method continues to be exploited. A development currently receiving attention is the coupling of discrete-ordinates calculations with Monte Carlo calculations to utilize the best features of both methods. Monte Carlo calculations can be performed in three space dimensions, and since certain regions of a system may require three-dimensional representation, coupled calculations may eventually be the common method of shield design.

WOMEN/ORNL

Kathy Nelson, economist

Design Repair with Several Criteria

It frequently happens that a perfectly good experiment is less informative than expected, because the experimental design was not carried out exactly as planned. Rather than using more drastic measures, like starting all over again, it is possible in a good number of cases to "repair" the experiment by retaining the data that have been collected and by adding a few more observations at critical points in the space of the controllable variables. Just where to place these points has been a subject on which the ORNL statisticians have some interesting ideas. They believe it makes sense to consider several different criteria, rather than just one, for deciding where to place the additional experimental points.

For a large class of frequently used mathematical models, called *linear* models, they consider the three criteria:

1. maximization of the minimum precision of predictions based on the model,
2. maximization of the average precision of predictions based on the model, and
3. maximization of the overall precision of the constants in the model whose values must be estimated from the data.

A computer program was written last year which will evaluate measures of the three criteria for points selected at random in the region of experimentation and print out an ordered list of the ten best points according to each criterion. The experimenter then selects a point which appears on all three "top ten" lists. The statisticians suggest that the point selected need not be in first place on any of the lists.

The coordinates of this point are appended to the original design so that the procedure can be repeated, and a set of new points is built up in this stepwise fashion. The process is terminated when the statistician and the experimenter agree that the design has been sufficiently repaired.

Life Sciences

Chemical Mutagenesis

— Cellular Program

Two of the major objectives of the Laboratory's new program in Environmental Mutagenesis are to obtain an understanding of the mechanisms of mutagenesis in various organisms and to devise a battery of tests that can be used to determine the genetic effects of exposure to environmental chemical pollutants on man. The widespread distribution in nature of such chemicals as mercury and DDT, their mutagenic effects in experimental test systems, and their accumulation at high levels in various organs and tissues of the human body, all stress the need for developing techniques to measure the long-term genetic effects of chronic exposures to environmental chemical pollutants. In this new program, 15 geneticists, 2 pathologists, a biochemist, and a biophysicist are working on a wide range of problems with such organisms as bacteriophage, bacteria, fungi, insects, and various mammals. One aspect of this work is the use of cultured human and other mammalian cells as model systems to develop techniques for measuring genetic damage in man directly.

The genetic effects of primary concern to man are heritable gene mutations and chromosomal rearrangements; both of these would increase the genetic load in the human population. Human and other mammalian cells in tissue culture are being used to develop assay systems that will measure the frequencies of various types of chromosome aberrations and the frequency of point mutations at specific loci. Another phase of the experiments consists of attempts to determine how the data obtained with such assays can be extrapolated to both the somatic and germ cells of man.

Assay systems are also being developed to detect gene mutations. The principal aim of this research is the development of sensitive procedures for assaying "silent" mutations, thus permitting an accurate determination of the spontaneous mutation rates in man and an indication of possible changes of mutation rates after human exposure to environmental agents.

Silent mutations are genetic changes that result in modifications of the gene product, but exhibit no obvious phenotypic effects. The presence of protein variants produced by such mutations has been shown by electrophoretic studies on a variety of biological systems. However, we do not know what fraction of the mutations affecting proteins may be detectable by electrophoresis. Furthermore, there is no available method for selecting silent mutations. The first task of this project is to determine what proportion of functional variants of enzymes also show changes in electrophoretic behavior.

One valid but tedious approach is to isolate a large number of cell clones, prepare cell extracts, and test each clone for the electrophoretic properties of a selected panel of enzymes. If a variant is found, the enzyme activity of the mutant clone can be studied further. A less arduous approach is to select functional variants before subsequent analysis by electrophoresis. Two selective techniques for variants with modified enzyme activities have been devised and proven feasible with an aneuploid cell line of Chinese hamster.

The first technique involves selective killing of a nonmutant parental cell population and rescuing the surviving mutant clones. A number of suspected mutant clones with deficient activity of the enzyme lactic dehydrogenase have been isolated. Among these, only a small fraction exhibits a change in electrophoretic behavior (staining intensity and mobility).

The second selective technique that has been tried involves mutagen treatment, single-cell cloning, and replica plating. The enzyme under study is glucose-6-phosphate dehydrogenase. In these experiments the putative mutants lacking this enzyme are killed with a special reaction mixture. Such mutants can be recovered from corresponding locations in the replica plates for propagation and further analysis.

Detection of chromosomal damage in human cells in tissue culture is a further objective of the program. Preliminary experiments are under way to develop and test a technique that permits exposure of human lymphocytes to chemical mutagens while they are in the in vivo environment of a host animal's peritoneal cavity. Human circulating lymphocytes are placed in a small cell-impermeable diffusion chamber which is subsequently inserted into the peritoneal cavity of a laboratory animal (host-mediated assay). The animal can then be treated with the chemical in question and the human cells removed later for cytological examination. If tests on chronic exposures are desired, it is possible to treat the animal for any period of time prior to insertion of the diffusion chamber.

In another series of experiments the chemical mutagen was fed to a host animal, and human cells were incubated in the animal intraperitoneally to permit an assay for the production of genetic damage.

Exploratory experiments with the host-mediated assay using human cells indicate that it can be used for directly studying the cytogenetic effects of potential mutagens on human cells exposed in an in vivo environment. The system also makes it possible to compare a compound's genetic effects on human cells with its genetic effects (e.g., production of dominant lethal and specific-locus mutations) on the host animal.

Both of these assay systems, when perfected, will probably become part of a battery of tests that will be used to determine whether a new chemical is capable of producing harmful genetic effects in man. Such tests will be performed before the chemical is approved for human consumption.

WOMEN/ORNL

Kim Bowman, statistician

Donna Michelson, chemist

Mammalian Program

The main objective of the Mammalian Genetics Section's work in chemical mutagenesis can be illustrated by comparing the present status and expected future of the program with the history of the Section's research on radiation mutagenesis.

The radiation genetic studies on mice were started at a time (1) when virtually nothing was known about gene mutation induction by radiation in any mammal and (2) when it was believed that the basic principles of radiation genetics were well understood from work on *Drosophila* and other organisms. Thus, it was generally accepted that gene mutation induction is independent of radiation dose rate and dose fractionation, is linearly related to dose, is incapable of repair, and shows no recovery with time. In fact, one or two noted geneticists stated that since this had all been worked out, the mouse program would be a waste of time and money.

Yet, as the mouse work proceeded, every single one of the above "principles" turned out not to be valid for mouse spermatogonia or oocytes or both. Each initial discovery of the failure of one of the accepted principles led, of course, to extensive exploration from the new finding. Thus, the discovery of a dose-rate effect led to a series of tests with a range of dose rates in both sexes and in different germ cell stages. From these and other experiments a whole set of new conclusions concerning repair and the factors affecting it has emerged.

It is a matter of record that these and other results have played an immediate and important practical role in estimating the genetic hazards of radiation in man.

In the chemical mutagenesis program, the complexities and surprises give promise so far of being even greater than in the radiation work. The all-or-none differences in response among strains and between the sexes are obvious examples. Another is the fact that very closely related chemicals may affect entirely different germ cell stages. Already what was believed to be one of the general principles of chemical mutagenesis has been found to be not valid for the mouse. It is clear that results with at least certain mutagens in microorganisms, and even in *Drosophila*, can lead to highly misleading generalizations as to what will happen in mice.

The program, so far, has concentrated on alkylating agents with known mutagenic effects in mice or other organisms. The main thrust of the work has been to measure accurately a variety of genetic end effects in the mouse (from gene mutations to chromosome aberrations) and to analyze the steps in the mutation process from the introduction of the chemical into the animal to the specific alkylation damage. The results have already shown that these steps are greatly modified by natural biological factors, such as sex and strain differences, as well as by external agents, such as treatment with other chemicals. Both types of modification provide tools for further analysis of the steps in the mutagenic process. As has already been mentioned, comparison of the genetic end effects obtained has provided one of the most dramatic of the results, namely, the demonstration that the ratio of frequencies of specific-locus mutations to chromosome aberrations induced by alkylating agents is

diametrically opposite to that found in microorganisms and *Drosophila.*

Another surprise has recently turned up as a result of a very accurate measurement of dose (ethylations per sperm head) for ethyl methanesulfonate in the mouse and parallel studies in *Drosophila.* The low gene mutation rate relative to the rate of chromosome aberrations in the mouse, compared with *Drosophila,* led most people to regard the mouse as insensitive to gene mutations. It turns out that the *absolute* gene mutation rate per dose (ethylations in target nucleus) is much higher (about two orders of magnitude higher) in the mouse than in *Drosophila.* A less exact dose estimate in *Neurospora* indicates an even bigger difference between the mouse and *Neurospora.* Thus, in contrast to generally accepted conclusions, the mouse appears to be vastly *more* sensitive to gene mutation in spermatozoa than either *Drosophila* or *Neurospora.* For chromosome aberrations the sensitivity of the mouse is astronomically higher than in *Drosophila.*

One of the main lines of research in the immediate future will be the exploration of these recently discovered large differences in response between mammals and other organisms.

— Analysis of Human Genetic Defects

Within the past two decades, human genetic disease has emerged as one of the major medical problems confronting our society. Infectious diseases no longer pose the serious threat that they historically have, principally as a result of advances in medical research and preventive medicine. Depending upon the authority one consults, there are currently about 100 to 200 known human inborn errors of metabolism, approximately 50% of which have been described in molecular terms; that is, the enzymic deficiency is known. The known number, however, reflects only a small fraction of the number that exist within the population. This is indicated by the fact that in institutions for the mentally retarded, approximately half the patients are there probably due to genetic causes; that is, they have similarly affected siblings or there are genetic implications from family histories, but they cannot be readily assigned to known inborn errors. In fact, if one restricts one's attention to the "severely" and "profoundly" affected individuals, the estimate of the genetic component rises to ~85 or 90%, and again the vast majority are "unknown."

The program initiated last year in the Biology Division has as its goals elucidation of the biochemical nature of these unknown human genetic defects as well as their detection and identification either prenatally by amniocentesis, in cultured cells, or in the white blood cells of infants. The experimental approaches are closely analogous to those of Beadle and Tatum upon which microbial biochemical genetics was founded: presumptive human mutants are selected, and their body fluids and cultured cells are analyzed for the presence of unusually high levels of ordinary metabolites. The experimental rationale is (1) that genetic defects usually result in an enzyme deficiency, (2) that an enzyme deficiency results in incomplete (or no) conversion of a metabolite to its normal product, and (3) that

the identification of an accumulant provides insight toward identifying the defective enzyme or genetic block. The final experimental step is to verify the enzymatic block in cells from the affected individual. Thus it is anticipated that many new human genetic diseases will be described biochemically as well as clinically and that such information will provide a basis for their control through therapeutic abortion, genetic counseling, or, in the future, genetic engineering. One thing is clear: their identification and biochemical description must precede any preventive approach.

It should be emphasized that mental retardation per se is not the subject under study. What is involved is the analysis of human mutation. Most of the recognized autosomal recessive human mutations result in mental retardation, but the term does not adequately describe the true situation. Most mutations in higher mammals produce multiple effects *including* damage to the central nervous system. The patients from whom the experimental material is derived for this study suffer from chronic toxemias, spasms, motor difficulties, and other severe symptoms affecting virtually all organ systems. Thus it could be described as a study of human lethal and sublethal mutations.

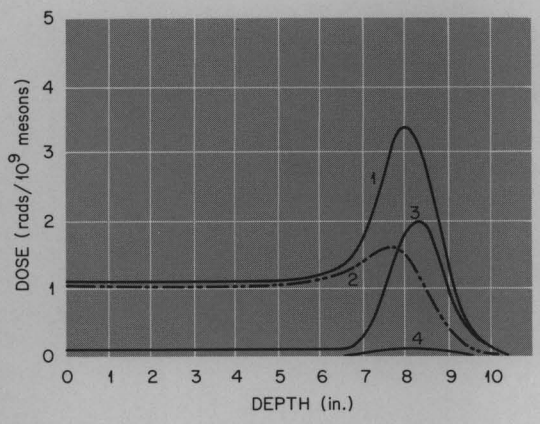
Urine and serum samples from suspected genetic variants are being analyzed daily for the accumulation of metabolites which absorb ultraviolet light or are ninhydrin-positive compounds or both. These two essential and highly specialized analytical systems have drawn upon the special expertise of personnel from other parts of the Laboratory. The high-pressure ultraviolet analyzer was designed and built by members of the Body Fluids Analysis Program and the Instrumentation and Controls Division of the Laboratory. One of the developers of the Technicon automated high-resolution amino acid analyzer currently is a member of the Molecular Anatomy (MAN) Program, and has been available for consultation.

It is worthy of note that two of the first ten individuals tested in the program exhibit abnormally high (10 to 100 times) accumulations, one involving a breakdown product of histidine and the other a product of tryptophan. Neither has been described previously. This has led to confidence in the analytical methods and the appropriateness of the selection of test individuals.

Pi Mesons in Cancer Therapy

Subnuclear particles known as pi mesons show great promise for improving the effectiveness of radiation treatment of cancer. For a number of years ionizing radiations such as x rays and gamma rays have been used to kill or inhibit the growth of cancer cells. Unfortunately, however, these radiations also damage the healthy tissue surrounding the tumor. It appears that irradiation by pi mesons can increase the damage to cancer cells and at the same time reduce the damage to nearby normal tissue cells. A negatively charged pi meson can be "aimed" to terminate at a predesignated point. Further, it has the property, not shared by any other particle produced in abundance, that after it stops in tissue there is a high probability it will be absorbed into the nucleus of an atom in the tissue and result in the disintegration of the nucleus into several

Calculations are made of the distribution and quality of dose delivered by pi-meson beams in tissue in order to evaluate their effectiveness for cancer therapy. Here the dose from a typical beam of pi mesons is shown as it varies with depth. Curve 1 is the total dose, curve 2 is the dose from direct ionization due to the pi mesons, curve 3 is the dose from charged particles resulting from nuclear disintegrations following meson absorption, and curve 4 is the dose from neutrons, also resulting from nuclear interactions. The charged particle dose (curve 3), which is much more effective in destroying tumor cells than the other components, is highly localized and thus may be directed precisely at the site selected by the radiologist.



fragments. These fragments deposit a large amount of energy in a small volume surrounding this point, making pi mesons much more effective in the selective killing of cells than other types of radiation. However, the precise nature of the effects produced in living tissue irradiated by pi mesons is not known. This is the information now being sought in current research.

At present the beams of mesons that can be produced are too weak to be practical for cancer therapy. However, meson "factories" are under construction at Los Alamos, New Mexico, Vancouver, British Columbia, and Zurich, Switzerland, to produce pi mesons in sufficiently large numbers for use in radiation therapy. Meanwhile, research is being directed toward determining the effects of pi mesons on living cells and the safeguards needed to protect patients and attending personnel.

As a part of a collaborative research program between ORNL and the European Organization for Nuclear Research (CERN), computers at ORNL are being used to simulate the conditions of radiobiological experiments performed at the high-energy accelerators at CERN. The computer calculations provide specific details of the physical interactions that occur within a target irradiated with a beam of mesons.

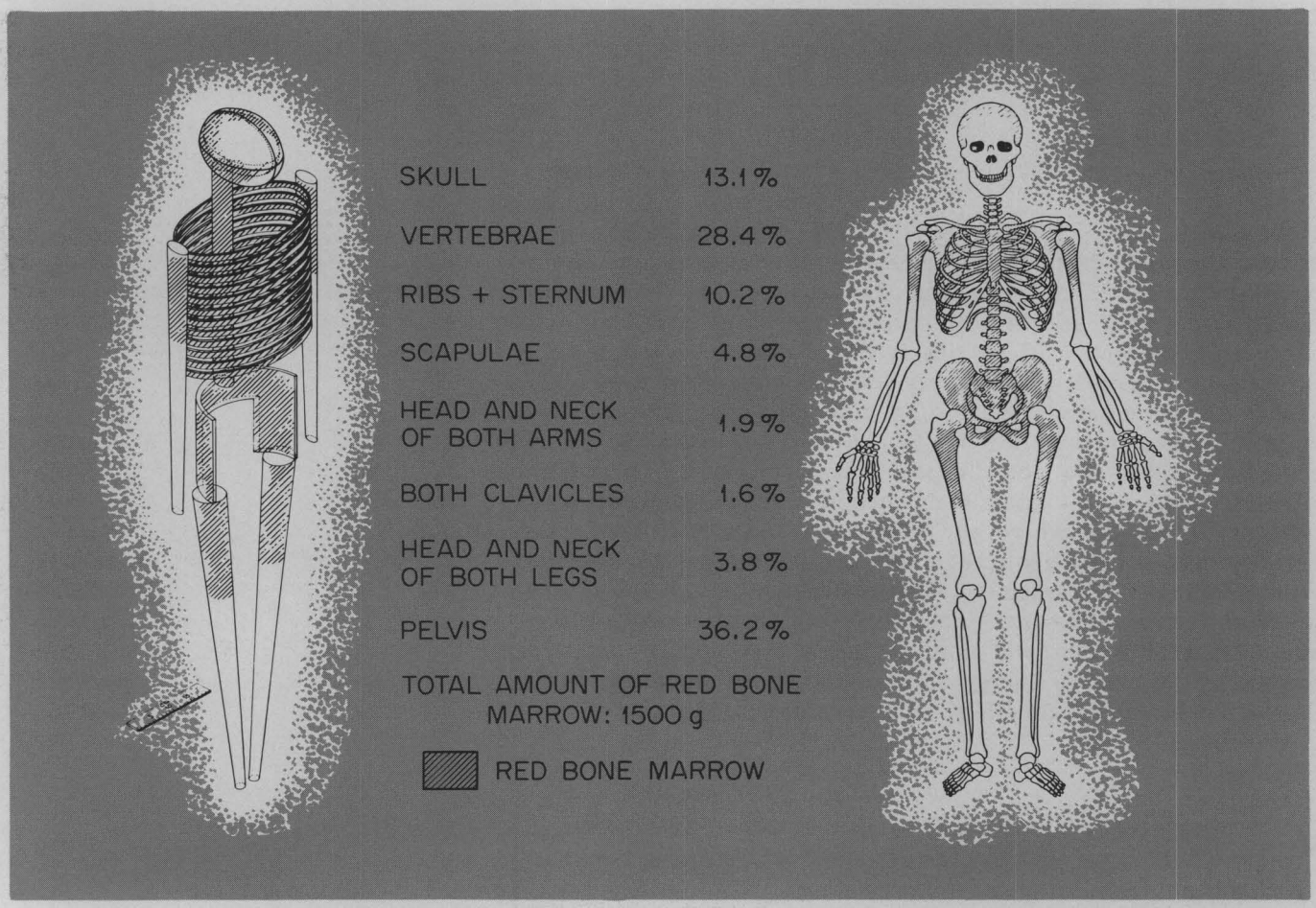
Experiments have been made at CERN by exposing mice (and also bean roots) to beams of pi mesons and comparing the effects with those produced from exposure to x rays. The mice are placed behind a water tank, and the thickness of the water is varied so that the biological effects can be observed at various depths. Energy deposited by charged nuclear fragments is much more effective biologically than energy deposited by other particles. The maximum dose from nuclear fragments occurs at about $^1/_2$ in. greater depth than the maximum of the total dose. Consequently, the maximum biological effect is not produced when the irradiated specimen is placed at the point where the total dose is a maximum. The difference between the depths at which the maximum total dose and the maximum nuclear fragment dose occur depends on the characteristics of the meson beam. A handbook is in preparation jointly by ORNL and CERN that will contain tables that can be used for determining the average energy and spread of those energies which will produce the maximum effect over the volume of a tumor.

Pi meson: a particle having 273 times the mass of an electron which can be produced by bombardment of a suitable target with a beam from a high-energy accelerator.

Internal Radiation Dose Estimation

Health physicists and mathematicians at Oak Ridge National Laboratory have used high-speed digital computers to provide more accurate information on dose from radionuclides deposited in the body. Such estimates of dose are important for medical use of radionuclides as well as for exposure of radiation workers and the general public. In particular, accurate estimates of doses to body organs are required as a basis for diagnosis or treatment of cancer by use of radioactive pharmaceuticals. The newer techniques use an idealized mathematical model of the body and its principal organs as a basis for the calculations. Previously, such estimates have been based on simple models for organs (spheres or ellipsoids) in a homogeneous medium, but the new methods use approximately the correct size, shape, composition, and density of the various organs. Because bone and lung tissue differ markedly from other tissues of the body in density and composition, the scattering of photons and the resulting energy deposition are found to differ significantly from the estimates formerly available for homogeneous media. A simplified model of the skeleton is used in the calculation.

Idealized model of the skeleton for computer calculations (left) and a more realistic representation (right) with percentages of red bone marrow found in the shaded portions of the bones.



Jane Setlow, biophysicist

Instruments

Hybrid Computer

The past year has brought the installation of an interesting analysis tool to the simulation laboratory of the Reactor Controls Department. The new addition is a hybrid computer, so called because it combines a differential analyzer (analog computer) with a digital computer, connecting them so as to permit the interchange of information and control signals. The machines were delivered in January 1970 and were accepted as a combined system in April of the same year.

The rationale for such a combination, as in folk tales of miraculous companions, is to create an assembly of which at least one member can do almost anything. Digital computers alone make clumsy modeling tools, and, in the recent past, the analog simulator which the Controls Department has run for 20 years has found a number of systems which have strained its modeling capacity. The active building blocks of the analog machine are high-gain operational amplifiers plus multipliers, function generators, attenuators, and comparators. Inventories of these elements range from dozens to hundreds. If one simulates a system whose components (e.g., pumps, accumulators, delayed neutron groups, animal organs, or circuit elements) have a reasonably limited population, the system will fit on the analog computer. One may then perform his experiments on the model in the expectation that its voltages will zig or zag in one-to-one correspondence with the perturbations expected of the variables being simulated. Of course the system to be simulated may

Hybrid computer in Building 3500; digital to the left, analog to the right. O. W. Burke and Ned Clapp check the oscilloscope readout while Peggy Johnson lends a hand at the teletypewriter.

Martha Stewart, chemist

involve hundreds or thousands of "parts," such as nodes in a continuum of reactor core, or stages in a fractionation process of some kind. It may involve complex function generation requiring large amounts of stored data, as in the equations of state for water. By adding a digital computer and creating a hybrid system, the user makes possible the storage of large blocks of tabulated data, thus greatly expanding "function generator" information handling. Moreover, where distributed properties must be dealt with, a few segments of a continuum can be set up on the analog machine, and the digital memory and programming can be used to share this piece of simulated matrix from boundary to boundary of the region of which it is typical. This operation is analogous to the procedure followed if the digital computer alone is asked to calculate the behavior of a continuum of this kind, but use of the analog as a huge subroutine greatly speeds up the process and allows a large measure of on-line access to the model, as is typical of the analog computer.

In the period since the hybrid machine was installed, another application has grown to be more important than anticipated. This is use of the machine for parameter determination, curve fitting, and model building, wherein theory is matched to experiment. One starts by feeding his experimental data to the digital machine, where it is stored and sent to the analog as needed for display on the large-screen oscilloscope. The current theoretical model of the system giving rise to the data is then programmed on the analog machine, the digital machine, or an optimum combination of the two. The output of this computer model becomes the input to a second channel of the four-trace oscilloscope display, and a comparison is made between the experimental and the simulated outputs. Model parameters can be changed by twirling knobs, with the fit optimized in a matter of minutes. If the model itself is inadequate or incorrect, changes can be tried on the spot. This procedure was first used on a few-stage model of a desalting plant evaporator, to improve the fit of stage-to-stage coefficients, and is still used in work for the desalting program as new models are developed and new data become available. This work was quickly followed by a similar process for a different purpose, namely, fitting theoretical neutron resonance parameters to data generated at ORELA. Interest raised by this work led to still another application, wherein much the same on-line fitting technique is used to optimize parameters in equations describing the behavior of charge carriers in solid-state detector material. In each case, the hybrid has presented a significant saving in time over previously used methods and has added the man-machine interaction which has made the analog so useful.

Future plans for this facility include extending the uses for data fitting, as well as beginning the simulation of large distributed-parameter systems as programs under development begin to run.

GeMSAEC as a Diagnostic Tool

— In the ORNL Health Division

Personnel from the Molecular Anatomy (MAN) Program and the Analytical Chemistry, Chemical Technology, and Health Divisions

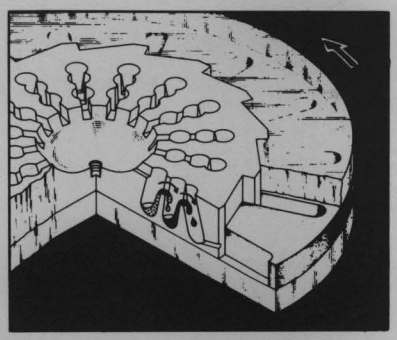
have cooperated in testing the GeMSAEC Fast Analyzer as a clinical tool. The GeMSAEC, developed at ORNL under the joint auspices of the National Institute of General Medical Sciences and the AEC, is a system that allows a number of chemical reactions to be initiated in a short time, permitting almost simultaneous absorbance measurements to be taken and then repeated at brief intervals. These virtues make the system an ideal instrument not only as a research tool but also for determining the activities of enzymes in body fluids.

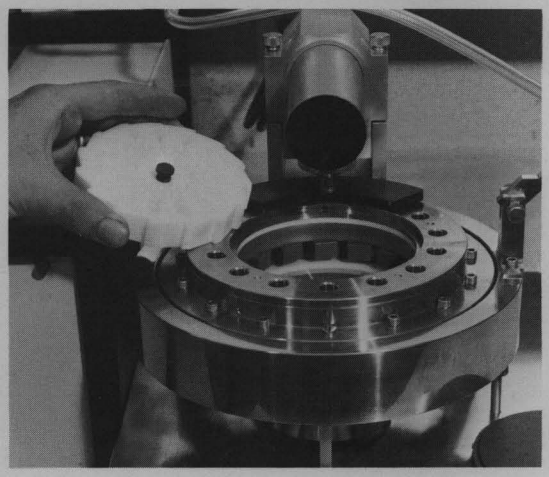
An integral feature of the analyzer is a Teflon transfer disk which, when loaded with sample and reagent, is positioned within a centrifugal rotor containing a number of quartz or glass cuvettes radiating toward the edge. As the rotor spins, the samples and a blank are almost simultaneously mixed with reagent and spun out to their individual cuvettes. As these mixtures move between a light source and a photomultiplier or other measuring device, the amount of light absorbed is measured for each position with each revolution of the rotor, at a rate of about eight times per second. This information is stored in a small computer where it is retrieved, after certain calculations have been performed, as a concentration or activity of the desired constituent in the sample of body fluid.

The classical method of determining enzyme activities in blood serum has been to measure the absorbance change over a 15- to 20-min period after the serum is mixed with a specific reagent. The unique value of the GeMSAEC lies in its ability to run a large number of these tests almost simultaneously and to determine the reaction rate more accurately in about one-third the time previously required. Very rapid computerized calculations can relieve laboratory personnel of much of the tiresome work of manual record keeping and at the same time lower the coefficient of human error. The recent introduction of an automatic sample and reagent loading device for use in loading transfer disks has improved the overall accuracy and performance of the system. Because elevated enzyme activities in a patient's blood serum can be indicative of such pathological conditions as a mild heart attack, liver disease, gall bladder disease, to name a few, it is foreseen that many GeMSAEC's will be used in hospital emergency wards and physicians' offices, as well as in regular hospital laboratories, to determine almost instantly the need for further action.

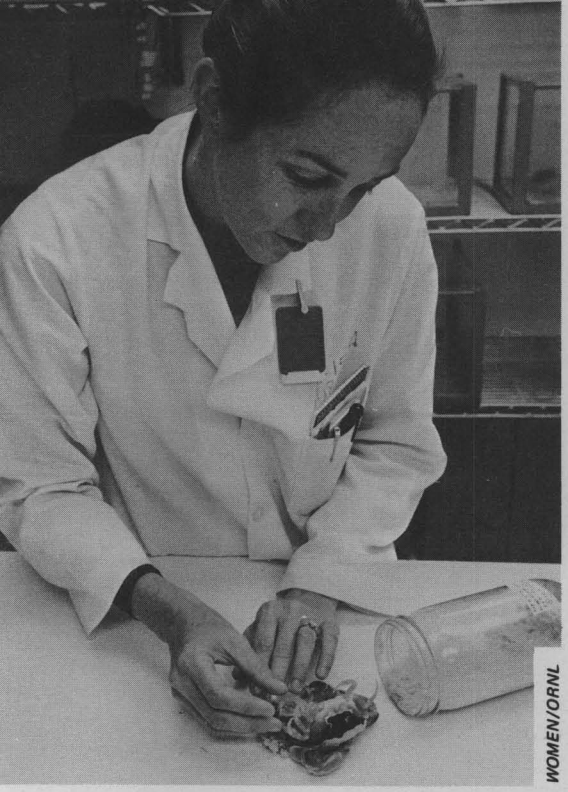
Perhaps the greatest commercial advantage of the GeMSAEC system lies in the extremely small amounts of sample and reagents required for a test. Normally only 300 μl of reagent and 2 to 50 μl of blood serum are used per test. This conservation of sample and reagent will potentially lower the present reagent cost per analysis by a factor of 10 or more in some cases. The small amount of serum used is of particular interest in pediatrics and to doctors treating burn patients where the available blood supply is limited.

During the past few months a small-scale testing program has been operated in the Health Division of the Laboratory. In this program six GeMSAEC tests are run on the sera of patients receiving their annual physical examinations. These tests include determinations of glucose, total protein, albumin, and certain of the enzymes.





The Teflon transfer disk, with its radiating holes for the specimen and reagent, is held here just above the rotor. At high speeds, the material is centrifuged out into the ring, from which it is then retrieved for spectrophotometric measurements. (Cutaway of disk, above.)



Dorothy Skinner Cook, biologist

It is likely that other tests will be added. Since this program is being run on a generally healthy population, few abnormalities have come to light, although several potential diabetics have been discovered and so notified. The program should be of greater interest in studying changes that develop in the body chemistries as a healthy population ages, and in attempting to predict the advent of various diseases.

This cooperative program with the Health Division has also been valuable in that it has given researchers an opportunity to observe the GeMSAEC under actual laboratory operating conditions, and thus to determine improvements in design to make better and smaller systems.

— In Space

The proposed Manned Orbiting Laboratory of NASA will ultimately include an Integrated Medical and Behavioral Laboratory Measurement System designed to enable NASA to determine behavioral and physiological effects of long-term exposure to zero gravity on the astronauts. This system is to include a clinical chemistry module for measuring up to 16 different chemicals in blood serum or plasma.

In cooperation with NASA, ORNL is now developing a small clinical chemical analyzer amenable to gravity-zero (GØ) operation for use in this program. The design of this GØ Analyzer is based on the GeMSAEC, using centrifugal force to contact blood serum or plasma with appropriate reagents in cuvettes located on the periphery of a spinning rotor. The principle is well suited for use in a zero-gravity environment, since the internally generated force field acts to hold the liquids in place.

All 16 analyses will be performed on a single blood sample in a single rotor and will require a total of approximately 250 μl of whole blood. A disposable plastic rotor will be used with the reagents prepackaged, in dry form, in the cuvettes. The first prototype system now under construction will require slightly more than 1 ft^3 of space. Data output from the systems will be to an on-board computer as well as a mechanical data printer.

Although this system has been designed to operate in a zero-gravity environment it will perform equally well on earth as a clinical instrument. The small quantities of blood required and the ability to perform many analyses on a single sample make the system ideally suited to pediatrics and emergency-room use. The system is compact and, when coupled to the mechanical data printer, is expected to be simple enough to operate and inexpensive enough to be attractive for use in small clinics or perhaps even in physicians' offices.

— In Cancer Detection

Much of the work that has gone into the development of the GeMSAEC is aimed directly at attempting to solve some of the

problems of the clinical laboratory, such as screening body fluids for evidence of cancer. Most of the tests planned by the MAN Program to be included in such a screen will be based on immunological reactions, many of which are difficult to automate.

At present several approaches are being explored in some detail. These include isopycnometric techniques utilizing very tiny polystyrene beads which have the interesting property of adsorbing antibody molecules from solution and holding them tightly on the bead surface. This thin film of protein has sufficient mass to change the density of the bead appreciably, and it will now be found to come to rest at a different level when centrifuged at high speed in a sucrose gradient. Each bead adsorbs about 600 antibody molecules from solution, but the adsorption of less than a tenth of that amount can be accurately measured. If the antigen that combines with the antibodies on the beads is now added, an additional layer is formed on the beads, and they "band" further down the gradient. The antigens used may be protein molecules or viruses, and the amount of material attached to each bead ranges from 10^{-12} to 10^{-16} g. This method, originated at ORNL, holds promise of solving many difficult problems of antigen detection.

Other techniques are also being explored including laser excitation of fluorescent antibodies attached to tumor cells, the use of fluorescence depolarization to detect antigen-antibody reactions, and adaptations of the GeMSAEC Fast Analyzer to radioimmunoassays.

Martha Gerrard, chemist

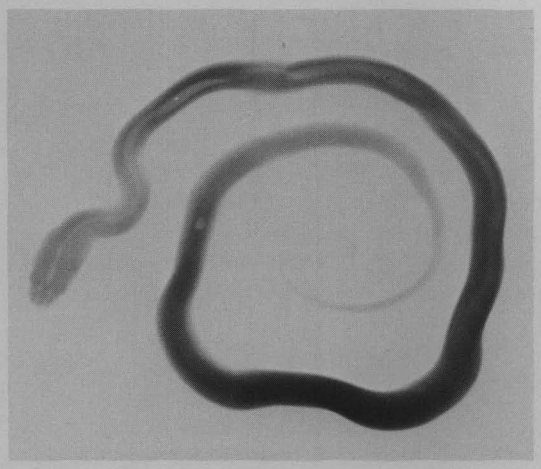
Neutron Camera

The most intense neutron radiography system ever built was installed at the Oak Ridge Research Reactor in 1970. The design and installation of the system were a joint effort of the Metals and Ceramics and Reactor Divisions, with the assistance of the General Engineering Division. The Metals and Ceramics Division operates the facility with the assistance of the Operations Division.

Neutrons, like x rays, penetrate matter selectively and hence can be used to "see" inside closed objects. Two differences make neutron radiography capable of inspections difficult or impossible with x rays. Highly radioactive objects, such as irradiation capsules containing experimental nuclear fuels, would blacken the film and obscure any x radiograph. Also, neutrons differ considerably from x rays in their attenuation by different chemical elements. Thus, neutrons can "see" some light elements that are transparent to x rays, yet neutrons penetrate heavy elements, such as lead, that stop x rays.

The system is installed adjacent to the reactor under 24 ft of shielding water. The neutron beam passes from the reactor tank to the camera through an air-filled collimator. The specimen is mounted next to an indium foil in a watertight aluminum cassette and lowered into the camera. Neutrons that penetrate the specimen induce radioactivity in the indium foil. After the exposure, the foil is removed and placed in contact with x-ray film, which then registers the image of the specimen. The radioactive image in the foil decays to a level that permits reuse of the foil the next day.

Black rat snake (Elaphe obsoleta). On the neutron image the digestive tract can be readily traced. In a similar x radiograph the bone structure hides this. Neutron radiographs can also be used to show muscle structure without interference by bones.



Helen Mateer, physicist

Curium-244 as a Heat Source

Curium-244 is of interest as a potential fuel for radioisotope electric power generators for space applications. Although the shielding requirements are greater for curium-244 than for plutonium-238, its power density in watts per cubic centimeter is about five times as great and its potential cost is lower.

The ORNL Isotopes Division encapsulated a 1-kW(t) $^{244}Cm_2O_3$ source last year to demonstrate the remote handling techniques necessary for fueling capsules for high-temperature applications such as advanced thermoelectric converters. The source consists of 14 hot-pressed $^{244}Cm_2O_3$ pellets approximately $\frac{1}{2}$ in. in diameter by $\frac{3}{4}$ in. long. The pellets were placed in an arc-cast tungsten capsule which was then sealed by tungsten—inert-gas fusion welding. All of the fuel preparation and encapsulation operations had to be carried out in an argon atmosphere containing less than 100 ppm oxygen to prevent oxidation damage to the tungsten components. The capsule is mounted in a vacuum housing and is surrounded by 200 layers of 1-mil-thick tungsten foils for insulation. For this test the temperature of the capsule is continuously monitored by an optical pyrometer system (using fiber optics) and thermocouples. The capsule will be operated in the test chamber at a temperature of 100°C for about a year to demonstrate the containment integrity of this type of capsule and the effectiveness of multifoil tungsten insulation. Also of interest will be data on the rate of helium release from the fuel as a result of the alpha decay of the curium-244.

Remote Terminals at ORNL

Over the past year the ORNL Computing Center has devoted considerable effort to the support of a variety of remote terminal systems, the objective being to make the large-scale computers more accessible to users and to make utilization of them easier. As a result, some 25 terminals of various kinds now have access to one or both of the major computer systems operated by the Computing Center.

Fourteen of these are IBM 2741 (IBM Selectric typewriter) terminals which talk to the 360/75 computer via eight dial-up telephone lines. The terminals are supported by the *C*onversational *R*emote *B*atch *E*ntry (CRBE, pronounced "cribby") System, which permits users to prepare files of information in "conversational mode" with the computer and to submit jobs to the computer for execution. Modifications to CRBE have been completed that will permit the system to recognize Teletypes as well as IBM 2741's. With this improvement, CRBE use is expected to expand greatly, and five additional telephone lines have been ordered to cope with the anticipated load.

Three IBM 2780 remote terminals are attached to the computers via private leased telephone lines. The 2780 terminal consists of a card reader, card punch, and line printer incorporated into one device. Two of these are located at the Naval Research Laboratory in

Washington, D.C., while the third is located at the Reactor Division at Y-12. These terminals are supported by the *R*emote *J*ob *E*ntry (RJE) System, which permits input to the computer via the remote card reader and output from the computer back to the terminal via the printer and card punch. An SEL-810B computer located at the Oak Ridge Isochronous Cyclotron (ORIC) Building is also attached to a central computer via a private leased telephone line. While the SEL computer is used primarily for data acquisition and processing at ORIC, it can be used for remote submission of jobs to the Computing Center in the same manner as the IBM 2780 terminals.

Under the auspices of the Division of Technical Information Extension (DTIE), an information storage and retrieval system (RECON) utilizing remote consoles has been implemented at the Computing Center. Five terminals, each consisting of a keyboard, TV display, and a Teletype, are attached to the 360/75 via a leased

These are just a few of the remote terminals around the Laboratory that tie into the PDP-10 in 4500N. Left to right from the top:

IBM 2741 Selectric in Civil Defense Project

Reactor Division's NOVAR

Data Acquisition computer at ORELA

Remote Job Entry (RJE) in the Reactor Division

RECON at Nuclear Safety Information Center

Culler-Fried Teleputer in Thermonuclear Division

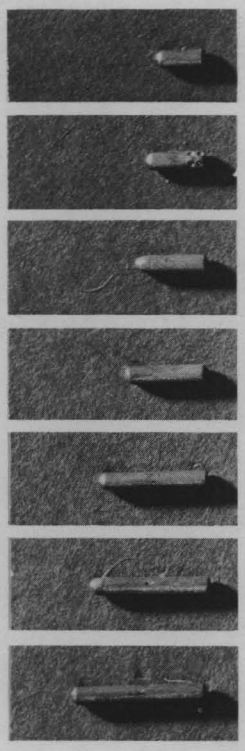
Chemical Technology Division's Teletype

Graphic Terminal at ORELA

private party-line telephone hookup. The terminals are located at ORNL Computing Center, DTIE, AEC-Washington, Westinghouse Bettis Plant in Pennsylvania, and Lawrence Radiation Laboratory at Berkeley. All have access to a data file consisting of *Nuclear Science Abstracts* for the years 1968—1970, stored on a data cell storage device attached to the 360/75. Searches may be made on the basis of subject matter (via key words), author, country of origin, and others. As of this writing, the Nuclear Safety Program of the Reactor Division is also planning to tie into the system.

The Thermonuclear Division is sponsoring the installation of the Culler-Fried Terminal System at ORNL. Two terminals will be involved, one at the Thermonuclear Division at Y-12 and the other at the Computing Center. The system is an interactive algebraic terminal with a keyboard for input and cathode-ray tube display for output. The system, developed initially at UCLA and being installed at ORNL by them, permits conversational computing with the 360/75 and includes capability for displaying graphs as well as numerical output.

At the request of the Instrumentation and Controls Division, the IBM Administrative Terminal System (ATS) was recently installed at ORNL. This system is accessible via phone lines and uses the same IBM 2741 terminals as the CRBE system previously described. The ATS system provides an interactive means of text input, editing, and printout for report preparation and similar applications.



A few of the neutron dosimeters, 2.5X magnification.

Neutron Dosimeters

As a result of discussions with members of the American Society for Testing and Materials Subcommittee on Neutron Dosimetry, the Isotopes Division has been fabricating neutron dosimeters that will permit standardization of flux measurements. Dosimeters have been made of isotopes of neptunium, uranium, plutonium, and scandium and of alloys of aluminum with cobalt, lutetium, and silver, all encapsulated in high-purity vanadium capsules. Capsule fabrication machining was performed under a microscope, as the capsules are 0.03 in. in outside diameter by 0.100 to 0.250 in. long, with an inside diameter of 0.030 in. Each capsule is loaded with 0.1 to 5.0 mg of the desired isotope. In 1970, dosimeters were shipped to NASA Lewis Research Center, U.S. Naval Research Laboratory, Pacific Northwest Laboratory, and Argonne National Laboratory and kept for use at ORNL. The small size of the samples will permit direct counting, thus eliminating the need for dissolution. The identity and weight of the target must be accurately known, and the outside of the capsules must be free of contamination.

Flowing Electrochemical Cell for Measurements at Elevated Temperatures

A new type of flowing electrochemical cell has been developed in the Reactor Chemistry Division for studying aqueous solutions at temperatures up to 300°C. The cell has no vapor space; any gases

involved in the electrode reactions, such as hydrogen, are dissolved in the appropriate solution prior to being pumped through the cell. The two solution streams, after passage through their respective electrode compartments inside a Teflon block in a metal pressure vessel, join in a junction chamber and leave the cell in one common stream.

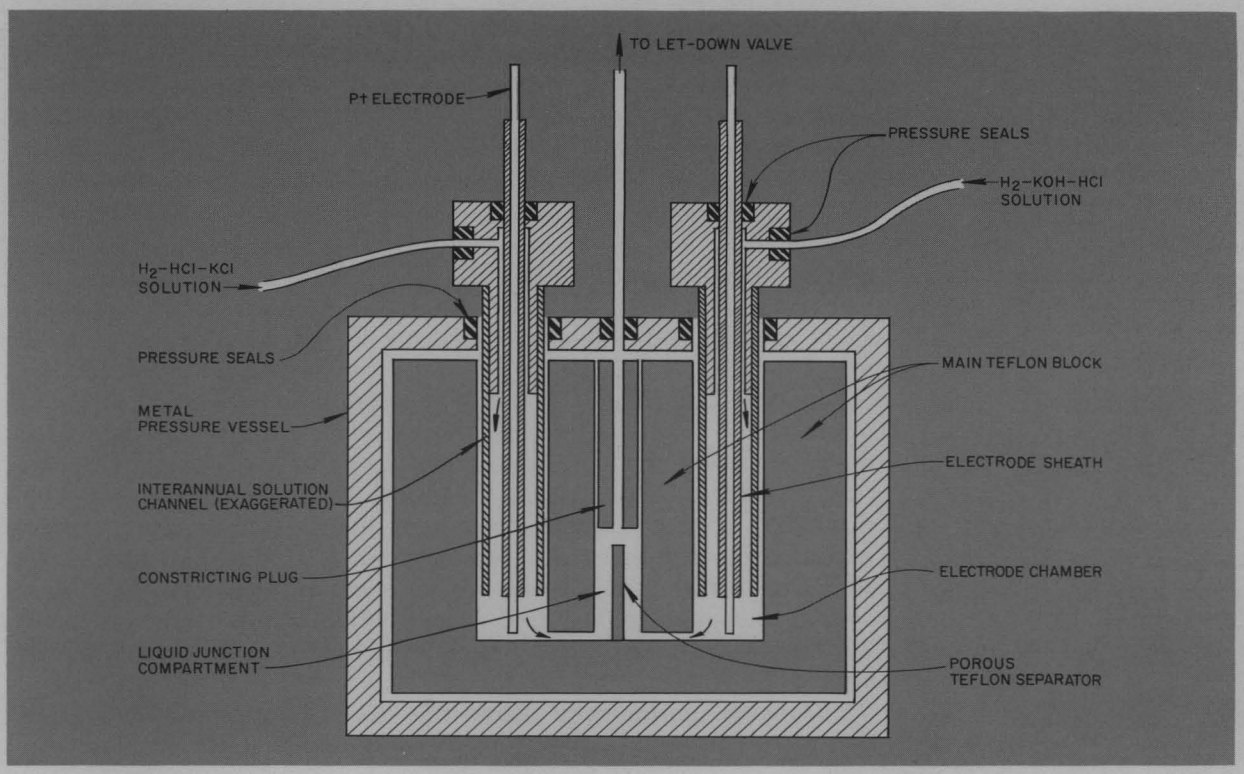
The cell is unusual in that it uses flowing solutions at high pressures. Since the cell has a small holdup volume, the residence time of the solutions in the cell is small, and the accumulation of impurities at high temperature is minimized. However, it is necessary that these flowing solutions do not conduct an appreciable electrical current between the metal pressure systems from which the solutions are pumped. A small insulated duct, therefore, made of expanded Teflon tubing, carries each solution through the cell to the electrode chamber. A small notch with a cross section of about 0.0001 cm^2 is cut in the outside of a Teflon layer shrunk onto each electrode. Another layer of Teflon is shrunk over the top of the groove.

The cell is also unusual in not having a vapor space. While necessitating prior equilibration of the solutions with any gases used in the electrode reactions, it allows the pressure in the cell to be changed freely and thus simplifies determination of the pressure coefficients of the electrode reactions. It also greatly simplifies high-temperature studies of solutions by eliminating any corrections for vaporization of solute or of water.

The cell, as constructed for the measurement of the dissociation of water, is shown schematically in the figure. Measurements are in progress in which the KCl concentration is being varied between 0.02 and 4.0 *m*. At temperatures between 0 and 50°C, where precise data are available, the logarithm of the dissociation constant is being determined with an accuracy of a few hundredths of a unit.

Nancy Cole, metallurgical engineer

Schematic drawing of flowing electrochemical cell used to measure the dissociation of water up to 300°C.



Nancy Betz, mathematician

Materials Research

Thermal Conductivity of Nuclear Fuels

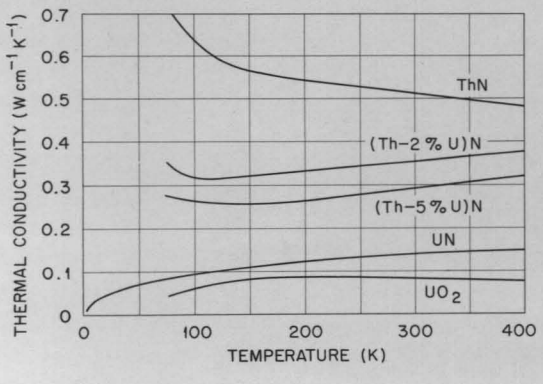
Better understanding of the performance of currently used nuclear fuels and clues for the selection of the most promising advanced fuels were the results last year of an experimental and theoretical study of thermal conductivity in the Metals and Ceramics Division. Thermal conductivity measurements were made from −315 to 300°F on single-crystal and polycrystalline uranium dioxide (UO_2). Comparison with previous measurements at higher temperatures and with other properties gives a complete picture of the mechanism of heat transport in this widely used nuclear fuel. Measurements over the same range on thorium mononitride (ThN), both pure and with uranium substituted for part of the thorium, have confirmed the predicted high thermal conductivities of these advanced fuel materials.

Before heat produced in a nuclear reactor can be converted to useful power, it must be transferred from its source in the fuel elements to the reactor coolant. The rate of this transfer is governed by the temperature and the thermal conductivity of the fuel, and the temperature is often limited by other materials present. Heat is conducted through solids either as vibrations of the atomic network or as motion of electrons; the latter predominates in metals, which have electrons capable of relatively free motion. Metallic nuclear fuels are limited in use by melting and structural changes at high temperatures and by severe distortions induced by irradiation, so ceramic fuels are the choice for power reactors despite their lower thermal conductivities.

The results on UO_2 show (1) essentially no difference between single crystals and polycrystalline material, (2) a broad maximum at about −60°F, (3) negligible contribution of electronic conduction, (4) low conductivity at very low temperatures because of magnetic interactions between the uranium atoms, and (5) a temperature dependence that indicates two components in the resistance to heat flow — interactions between the vibrations and interference by the magnetic uranium atoms. The high-temperature magnetic effect explains why the thermal conductivity of UO_2 does not deteriorate seriously during use as a nuclear fuel; each magnetic uranium atom acts like an impurity atom, so when uranium atoms become replaced by fission product atoms, the conductivity is not significantly altered.

Thorium mononitride shows the strong binding between atoms that gives the high-temperature stability and strength characteristic

Thermal conductivity of ceramic fuel materials. The advanced fuel uranium mononitride has free electrons capable of carrying heat, so it conducts better than the current fuel, uranium dioxide; at the higher operating temperatures of the fuels, the difference is greater. However, thorium mononitride, which has no magnetic atoms to interfere with electronic motion, is a far better conductor.

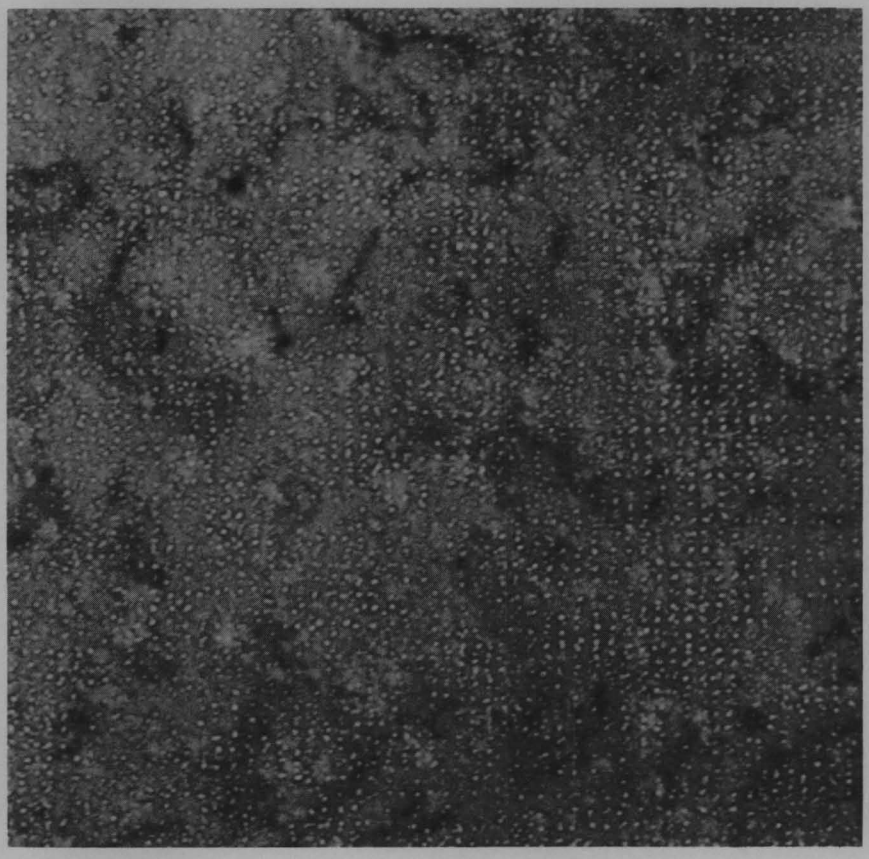


of ceramics. However, electrons in excess of those needed for binding impart metallic conduction to the compound. The similar uranium mononitride (UN) is a promising nuclear fuel because it is capable of electronic conduction, but the magnetic uranium atoms also interfere with electronic motion. Having no magnetic atoms, thorium mononitride has a much higher electrical conductivity than the uranium compound, and now ORNL has verified the high thermal conductivity predicted from the electrical measurements. Also, substitution of uranium for up to 5% of the thorium, as is necessary if the material is to be used as nuclear fuel, still leaves the thermal conductivity much higher than that of uranium mononitride.

A by-product of the ORNL program is a new and simple preparation of the nitrides. A rod of the metal is zone melted in nitrogen — that is, the rod passes through a short induction heating coil, causing a molten zone to move the length of the rod. The molten uranium or thorium reacts with the surrounding nitrogen and solidifies to the solid nitride. Normally the synthesis requires several steps involving handling and compacting very reactive fine powders.

Arlene Kibbey, chemist

Molybdenum irradiated in the EBR-II at about 585°C to 2.5 × 10^{22} neutrons/cm^2 (>0.1 MeV). Most metals and alloys irradiated under comparable conditions show voids — holes too small to be visible except with the electron microscope. Usually the voids are randomly distributed, and sometimes they are clustered about structural defects. However, in molybdenum, niobium, and tantalum, the Metals and Ceramics Division has found that the voids form a regular array, a superlattice parallel to the arrangement of atoms in a body-centered cubic crystal lattice. The electron micrograph shows the voids in molybdenum magnified 100,000 times.



ENVIRONMENT

ORNL-NSF Environmental Program

Problems of dimishing resources and a polluted environment are relatively new phenomena in the United States. They are largely a direct result of the upturning population curve, with the concomitant increase in economic production and the use of energy.

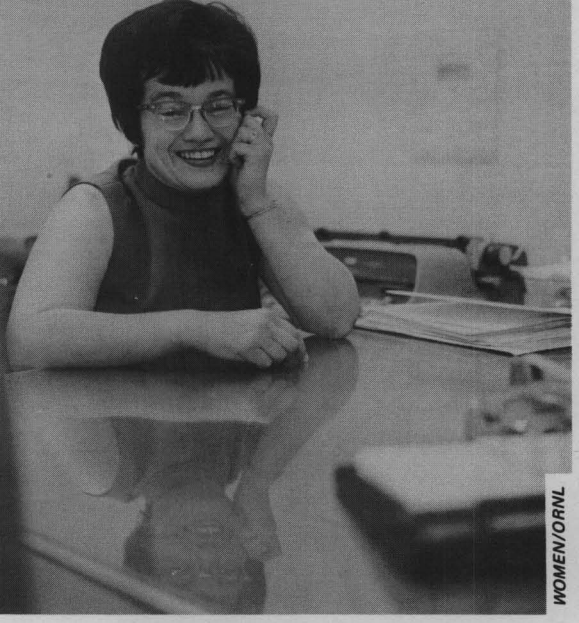
The Oak Ridge National Laboratory—National Science Foundation Environmental Program, established in the summer of 1970, is concerned with both conservation and pollution abatement. This program, comprising six teams, is concentrating on two broad areas of technology assessment: electrical energy and the management of materials; at the same time it is establishing research techniques and methods to develop and handle the information needed for socio-technical problem assessment. These methods are concerned with the establishment of environmental indices, regional modeling, an environmental information center, and education and communication. The ultimate goal is to provide the public and its policy makers with the technical and economic information they need to choose among the alternatives for improving the quality of the environment.

Electrical Energy and Its Environmental Impact

Electricity is a basic ingredient in material affluence, and yet from resource extraction to final use, it is one of the most important contributors to environmental degradation. Further, the large volume of waste products contributed to the environment by the production of energy is not easily handled, nor are our energy resources themselves unlimited.

The energy team of the Environmental Program is addressing itself to three aspects of the problem: First, they are determining the total social cost of electricity, including such nonmarket costs as damage to the amenities, property damage, damage to human health, and ecological damage, looking at the four principal fuels, oil, gas, coal, and nuclear. Second, they are constructing an econometric demand model of electrical energy to determine the effect on energy demands of higher prices. And third, the energy team is examining alternatives to increased consumption, specifically, more efficient residential use of power.

The material resources and recycle team views most forms of pollution, as well as the rate of depletion of our resources, as the result of mismanagement of materials in terms of social optimum. It is seeking to establish the priority for recycling specific materials by



Lorraine Abbott, chemist

developing a Materials Criticality Index, which is a composite of the attributes deemed most significant of each material considered.

The MRR team also seeks to describe the flow of materials through our socioeconomic system, as well as the external influences that affect this flow, such as incentives introduced in the form of taxation or price supports. After analyzing the flow, the team seeks the means to abate environmental insults resulting from it and also to effect greater resource conservation either through substitution for scarce or harmful materials or through recycle.

The environmental indices team is attempting to devise quantitative indicators of the quality of the environment. They have started on an air quality index and are establishing a gage that can be communicated to the public through the mass media each morning, indicating the amount of harmful pollutants in the air.

Studies in regional modeling include the collection of physical, ecological, demographic, economic, and social data on a specific region of the country and then, with the help of a computer, predicting the effects of any perturbation on the region and its environment. One use of the model has been the calculation of loss in agricultural productivity in a particular county that would result from the emissions of a coal-burning power plant if such a plant were to be sited there.

Many specialized information systems now exist that contain data necessary for environmental studies. It is the province of the information team of the ORNL-NSF Environmental Program to identify the sources of such information and develop computer programs that can handle many diverse inputs. The result is a growing Environmental Information Center at the service of the problem-solving teams.

The Cooperative Science Education Center in Oak Ridge, an operation situated in Oak Ridge that serves the state school system in a scientific enrichment program, is also under subcontract to the Environmental Program. It has undertaken to develop and maintain a relevant communication in Tennessee between science and society. It is also providing environmental education and training services for teachers in the state educational system. A statewide air monitoring project involving 25,000 high school students, instigated by the CSEC, proved successful enough in 1970 to warrant similar systems in 1971 in other states as well as its repetition in Tennessee.

The problems under study by the Program are not wholly separable, and ameliorating one environmental problem can aggravate another. And so technology assessment is approached as *socio*-technical research, that is, with the recognition that many problems stem from traditions, institutions, governmental regulations, and social prejudices. Regional management of solid wastes, for instance, may not be so much a technical or even economic problem as one of social prejudices and resistance to change by governmental bodies.

The Mercury Report

One of the major assessment activities of the Environmental Program was directed toward an understanding of both mercury in

the environment and the methods by which such an evaluation is made. Several groups considered various aspects of the problem, the first of which was the environmental and societal flow of mercury. The most important environmental sources were found to be chlor-alkali plants, seed-dressing agents, smelting operations, fossil fuel combustion, and geothermal processes. The U.S. societal demand was then divided into dissipative and potentially recyclable uses, and these were balanced against the available market sources. This model allowed several important externalities to materials operations to be identified, and emphasis was then placed on the social costs of present use practices and on those factors (prospecting subsidies, tariff regulations, market needs, etc.) which would apply to recycle potential and to alternate use and materials technology. An accountability system for mercury and other persistent toxic substances similar to the one used by the Atomic Energy Commission for fissionable materials was recommended.

A second consideration involved the challenging problems that arise when mercury levels in environmental materials are measured. These difficulties relate not only to the variety of samples and to the very low quantities of mercury that are encountered but also to the recognized volatility of mercury compounds and to their tendency to absorb on particles and surfaces. The latter characteristics thus place great importance on the sampling, sample handling, and chemical treatment portions of any analytical scheme. Since such considerations have generally not been given sufficient attention, it became clear that many reported values could be inaccurate by as much as a factor of 10. There thus appeared to be a major need for research into the techniques for sampling and sample storage and for the development of standards and procedures of representative types that could be widely circulated for correlative analyses. An evaluation of several analytical measurement techniques was also made, and several promising methodologies for various circumstances were identified.

Finally, existing data for "background" and "contaminated" situations in air, water, rocks, soils, sediments, sludges, fossil fuels, plants, animals, foods, and humans were drawn together and evaluated. It was concluded that mercury, in whatever form, is potentially exchangeable among the air, land, and water phases and that, like all toxic metals, it is an essentially indestructible pollutant. Details were then provided concerning the toxicity of mercury and its compounds, and these were related both to the present levels to which man, in particular, is exposed and to the existing standards and tolerance limits.

This major assessment activity disclosed many important problems and helped identify specific areas requiring either additional technological or other research. It also helped bring together a number of people from a variety of backgrounds who learned to talk and work together on a given problem. Although the final report itself proved to be valuable to many persons and agencies outside ORNL, the acquired experience in, understanding of, and demonstrated ability to do interdisciplinary work were undoubtedly the most important benefits within ORNL.

Marion Ferguson, chemist

International Biological Program

The role of the Laboratory in the International Biological Program is both large and complex. The Division of Ecological Sciences is central headquarters for the Eastern Deciduous Forest Biome program. This broad research effort is attempting to understand the total aspects of biological productivity in terms of its relationship to human welfare. By "biological productivity" is meant the fixation, transfer, flow, and cycling of energy and materials through the complex of living and nonliving components of ecosystems. Although these processes are similar everywhere, different parts of the world find them differing in organisms and environments. Knowledge of productivity, including the production of food (both plant and animal), fiber, building materials, and so forth, is important for man's physical needs, but portions of the earth's surface also furnish living space, scenic vistas, recreational areas, and wildlife habitat as well. These tangential features impinge directly on man's welfare as a burgeoning population places greater and greater pressures on society.

In the eastern United States, the great region of temperate deciduous forest is a complex of aquatic and terrestrial ecosystems that collectively covers about a third of the country, but at present supports about two-thirds of the people. In the common, yet unique, situation where land and water systems interface, often referred to as a watershed, research is aimed at determining the uptake, transfer, and discharge rates and pathways of critical mineral elements, potential pollutants, and biological materials so that the functioning of the total system can be described mathematically in what is called a "systems model." Then, using high-speed digital computers, the mechanics of the ecological system can be simulated, and by running such a model for specified lengths of hypothetical time, it is often possible to predict the ultimate outcome of present-day decisions in resource management. This approach is rapidly coming to be recognized at various levels of government to be essential to sound planning and wise resource utilization.

From the central group at ORNL, the integrated research program radiates to five major sites within the biome region: Oak Ridge, comprising areas and facilities of the AEC; the Coweeta Hydrologic Laboratory of the U.S. Forest Service and the Duke Forest near Triangle Research Park, both in North Carolina; Lake Wingra at Madison, Wisconsin; and Lake George, near Troy, New York. Funding for the project is through the National Science Foundation under an interagency agreement with the AEC.

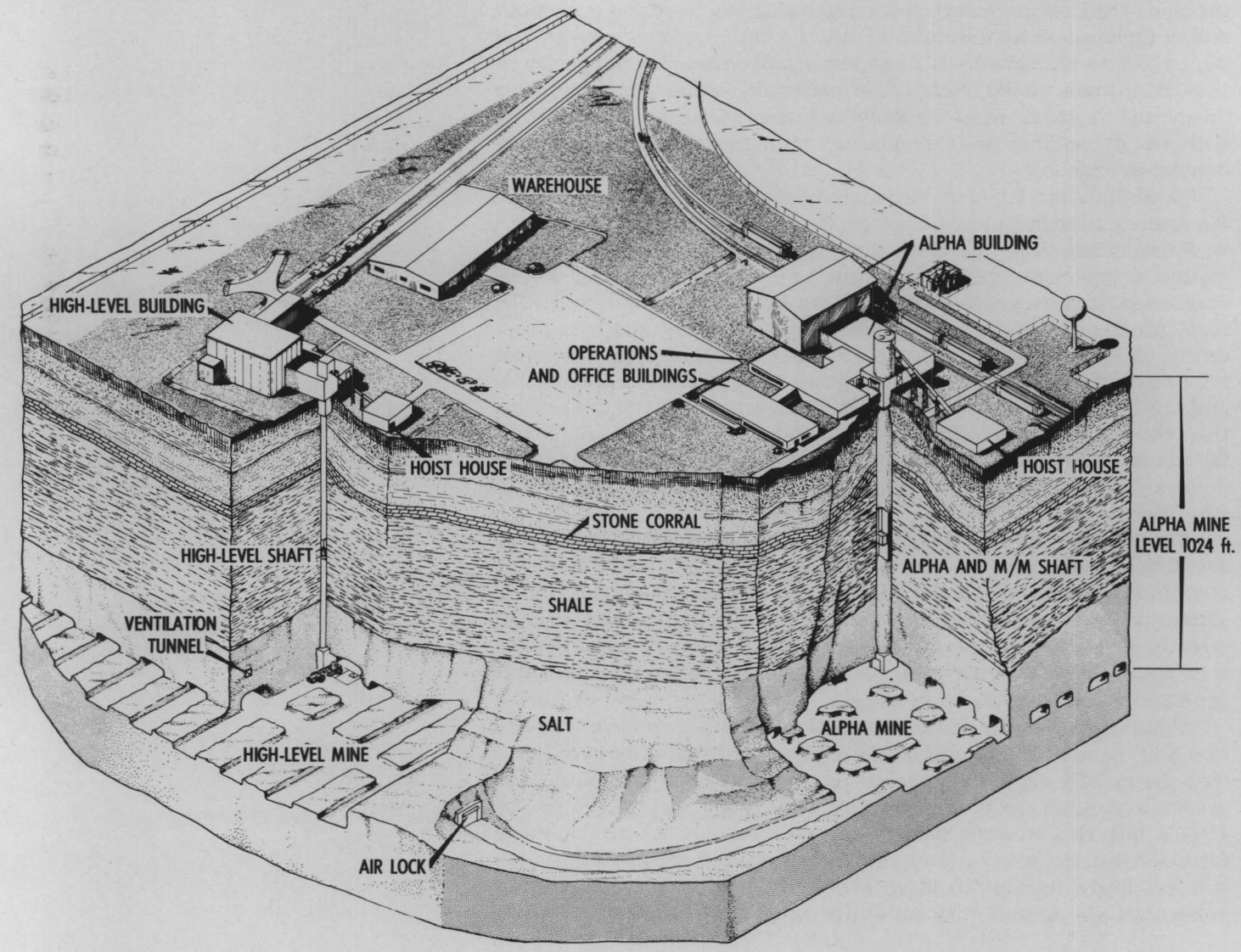
Waste Repository in Salt Mines

During the very early stages of the nuclear power reactor development program, it was recognized that unless the problem of disposing of the large quantities of highly radioactive fission products resulting from the chemical reprocessing of spent fuel was solved, the use of nuclear power as a source of energy would be seriously impeded. The disposal of these wastes is, indeed, a formidable problem; they require heavy shielding during any handling operations and complete and total isolation from the biological environment for periods of several hundreds of thousands of years. The longevity of the hazard associated with these materials implies that any true "disposal" system must reliably achieve the required isolation without depending on surveillance, monitoring, or, indeed, any control by man.

In September 1955, a National Academy of Sciences—National Research Council committee of geologists and geophysicists, which was established to consider the possibility of disposal of radioactive wastes in geologic structures within the continental United States, concluded that natural salt formations at specific depth were the most promising potential disposal sites. Several advantageous properties of salt and salt deposits led to this conclusion, the most important of which was that salt deposits are essentially impermeable and are completely isolated from circulating groundwater. Following this recommendation, ORNL commenced a series of field and laboratory studies that culminated in 1965—1967 in a full-size field demonstration experiment called Project Salt Vault. This experiment, which was carried out in a disused salt mine at Lyons, Kansas, used irradiated fuel elements from the Engineering Test Reactor to simulate actual solidified wastes and successfully demonstrated the techniques and much of the equipment for handling highly radioactive materials underground. In addition, a large quantity of data directly applicable to the design of an actual waste disposal facility was obtained by electrical heater experiments simulating the heat generation characteristics of wastes.

Following the successful completion of this experiment, some feasibility studies were undertaken which served primarily to indicate that the rapidly expanding nuclear power industry would require the availability of an operating waste repository by the middle of the 1970's but that a single facility to accommodate all of the waste from the entire United States through the end of the century would still be fairly modest in size. The best location for this facility appeared to be in and adjacent to the mine at Lyons, Kansas, which

The Atomic Energy Commission has announced plans for a National Waste Repository to be established near Lyons, Kansas. An inactive mine of The Carey Salt Company will be used for disposal of alpha-contaminated solid waste. New space will be mined for the disposal of high-level solidified waste. The proposed repository is the culmination of the Laboratory's research on disposal of radioactive waste in salt formations.



Jean Redman, physicist

was used for the Project Salt Vault experiment. Based on these findings, preliminary conceptual design of a facility was commenced during the summer of 1969.

In March 1970, the AEC interrupted this design effort with the question, Could the capability of the salt mine waste disposal facility be expanded to include the handling and disposal of fairly large volumes of solid low-level wastes, principally those containing long-lived transuranium elements like plutonium, being generated at AEC installations? An affirmative answer to this question gave rise to the following events:

First, in June the AEC announced publicly the tentative selection of the Lyons site for this purpose and its intention of seeking Congressional approval of the project for fiscal year 1972.

Second, a very extensive and detailed examination of the geologic, hydrologic, and ecologic characteristics of the site was initiated in cooperation with a large number of federal and Kansas State agencies and institutions. In compliance with the National Environmental Protection Act of 1969, a draft Environmental Impact Statement was prepared and has now been circulated to all federal, state, and local agencies having jurisdiction or special expertise in areas related to the facility.

Third, the architectural-engineering services of Kaiser Engineers of Oakland, California, were secured under contract to develop a detailed conceptual design for the combined disposal operations for solidified high-level fission product wastes and packaged low-level plutonium-contaminated wastes.

As presently visualized, the Federal Waste Repository will utilize the existing 180-acre Carey mine and approximately 900 acres of the adjoining salt formation. In addition, a buffer zone at least 1700 ft wide will be established around the periphery of the site through the acquisition of subsurface mineral rights. Although the facility will have the capability of storing all of the high-level wastes to be generated in this country through the remainder of the century and large volumes of plutonium-contaminated wastes, it will be operated as a demonstration while all aspects of the design and operational procedures are verified. The mine will be designed so that within 60

to 100 years the salt processes of deformation and recrystallization will have caused reconsolidation of the entire area and the wastes will be completely isolated from the biological environment.

The principal components of the Repository are: the existing salt mine, situated about 1000 ft below the surface, which will be used for storage of the low-level (alpha) wastes; a building in which the alpha waste packages are received, monitored, and transferred to the existing mined area by direct handling techniques; a newly mined area for burial of the high-level wastes; a building equipped to receive containers of solidified high-level wastes and transfer them remotely from their shipping casks to the mine level; and various support facilities, such as operations and office buildings, a warehouse, and those other services and utilities that are required for mining and underground storage operations.

The alpha waste receiving building will provide earthquake- and tornado-resistant facilities in which waste packages can be removed from returnable cargo containers, assayed, decontaminated or repaired as necessary, and lowered into the mine. The alpha waste transfer shaft, actually one of three completely independent compartments in a shaft which is also used for transferring personnel and materials and for admitting ventilation air into the mine, will terminate in an alpha confinement room at the mine level. Here, the pelletized packages of waste will be unloaded from the hoisting cage by a forklift truck and transported to the disposal room, where they will be unloaded and stacked. When an area or room has been completely filled, it will be backfilled with salt and sealed. The alpha facility will have a capability of handling 1 million cubic feet of waste per year, and the presently mined-out area will provide space for a total of about 20 million cubic feet.

The solidified high-level wastes, sealed in steel containers from 6 to 14 in. in diameter and from 2 to 10 ft long, will be transferred by rail to the Repository in shipping casks weighing up to 100 tons. The containers will be remotely unloaded in the receiving building and individually lowered into the mine through a 40-ft-diam shaft which is used for no other purpose. In the mine, the containers will be moved to rooms especially mined in the salt formation and remotely deposited into holes drilled in the floor using a self-propelled and shielded waste transporter. The spacing between the containers will be such that the radioactive decay heat will be dissipated without causing excessive temperatures in the salt or in the neighboring geologic formations. After the burial area of a room has been fully utilized, the room will be backfilled with crushed salt obtained from the excavation of further rooms and sealed from the remainder of the mine.

Thermal Effects Program

The Ecological Sciences Division of ORNL established a discrete thermal effects research program in early 1970 to arrive at sound ecological data regarding the effects on aquatic life of effluents from electric power plants, and to establish a factual basis on which necessary control measures could be taken. The program is being funded by the USAEC Division of Biology and Medicine through its Environmental Science Branch. The research is coordinated with studies at other AEC laboratories, at universities under AEC contract, and with other federal agencies concerned with this problem. The staff engaged in the ORNL study is contributing to power plant siting decisions and water quality investigations currently being undertaken by the National Academies of Science and Engineering.

There is no single concept of "thermal pollution" as it is referred to in the broad discussions of energy production. It is, in reality, a complex of problems involving many disciplines both in its study and in its control. The principal charge of the ORNL study, however, is the examination of biological changes, those caused by uncontrolled disposal of heat to water bodies, that can be considered deleterious. These effects, many of which have been identified in scientific reports, range from biochemical changes to declining populations of some important species. Changes that may be detrimental to other water uses, such as recreational fishing, are also of concern. Thus, temperature change to the extent that it conforms to the general definition of pollution, that is, as an addition that degrades the resource for other users, is the main object of study by the program.

In conducting its integrated field and laboratory studies the thermal effects program at ORNL will try to develop a predictability that will define quantitative ecological boundary conditions or limits having direct utility to the power station planner. Such ecological limits, if provided and used at the proper stages of early planning, can have the same utility for design engineers as the basic materials limitations they work with every day.

The realities of power plants are thus considered to be the objective, rather than just an encyclopedia of temperature effects in biology.

To implement the new program, new facilities were necessary. Existing aquatic ecology laboratories in Building 2001 have been renovated to accommodate nearly wall-to-wall fish tanks for laboratory experimentation. These are fed by spring water pumped from Chestnut Ridge. Six $\frac{1}{4}$-acre fish ponds were constructed in the 1500 area of the X-10 site in June 1970. They were the first of 12 that the 1500 area can eventually accommodate. These ponds have already served as valuable rearing ponds for experimental fish.

Moreover, a major new Aquatic Ecology Laboratory is scheduled for construction near the ponds by 1972. The $440,000 facility will

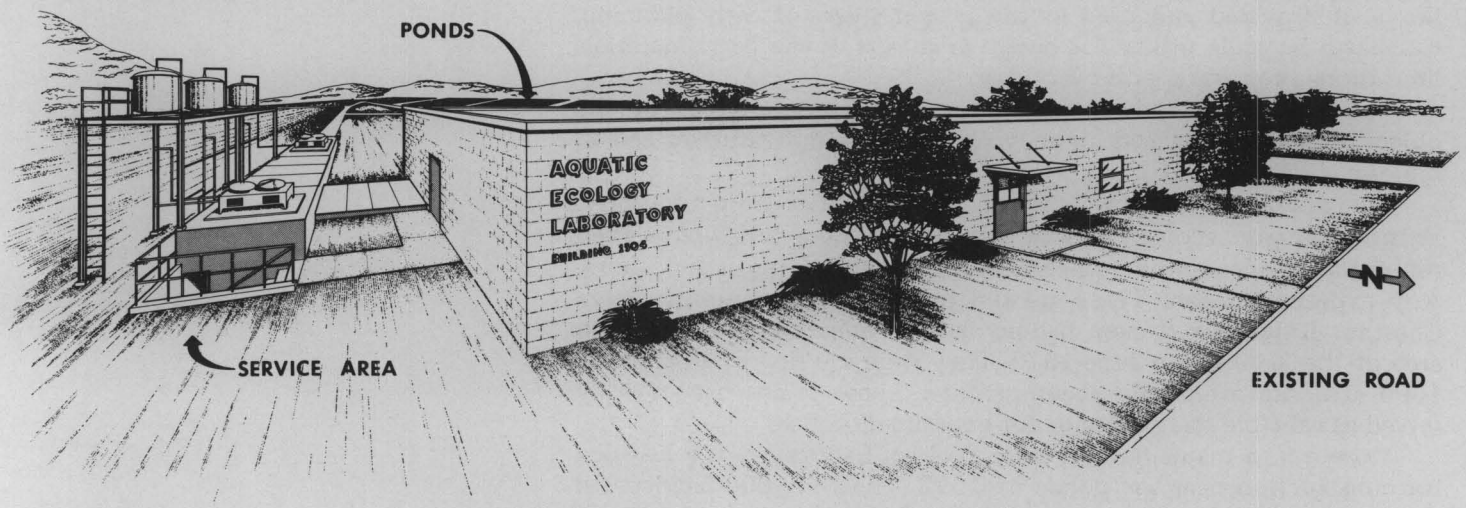
house experimental tanks, water supply, and control equipment specifically designed to study the effects of temperature and other potential water pollutants from the atomic energy industry on fish and other important aquatic organisms. The facility will feature a unique water supply and pumping system for nearly 100 tanks in which temperature fluctuations simulating those found near thermal discharges can be produced individually through use of elaborate mixing valves and a programmed PDP-8 digital computer. Thus, the most prominent feature of man-made thermal modifications, namely, the abnormal temperature fluctuations on hourly, daily, and seasonal time scales, can be studied.

The principal field study area is currently TVA's 960-MW Bull Run Steam Plant just outside the Oak Ridge Reservation and on the Melton Hill impoundment of the Clinch River. While TVA has conducted several evaluation studies there since the plant began operation, the temperature differentials between reservoir and discharge allow analysis of many biological processes not quantified by earlier work.

One biological process chosen for study there is temperature selection by unrestrained fishes in the field. The plant discharges cooling water through a short canal into an embayment. There is heavy use of these waters by fishermen, suggesting that fish are attracted, perhaps by selecting favorable temperatures. Fish collections with an electric shocker have confirmed temperature selection, showing that gizzard shad, for example, maintained body temperatures close to the maximum temperatures available to them in the wintertime by congregating in the discharge bay. The fish promptly dispersed when the plant was shut down for spring maintenance.

Laboratory personnel have developed a new device for continuous monitoring of fish movements and the water temperatures they select. The Instrumentation and Controls Division has designed an ultrasonic fish tag that measures and transmits temperature data. This device will allow definition of temperature variations that a fish normally endures, as well as those he chooses to avoid. The tag represents the first use of a custom silicon integrated circuit at ORNL. It is implanted surgically in the body cavity of adult fish,

Architect's drawing of proposed Aquatic Ecology Laboratory, in which the long-term effects of elevated temperatures on freshwater biological systems will be studied by the Division of Ecological Sciences.



with the temperature sensor allowed to protrude through the body wall. Additional field studies are currently under way on zooplankton pumped with cooling water through the condensers and then subjected to intense predation by fish masses in the discharge area.

During the lag period before field equipment and laboratories became available, the principal effort of the program was to evaluate existing information. This process is never complete, but the timing of other activities provided a valuable opportunity for some needed introspection. Essential ties within ORNL were enhanced through preparation for the AEC, with the assistance of the Environmental Quality Study Project staff, of a draft of a multidisciplinary program plan for the study and evaluation of thermal discharges and their effects. Members of the Divisions of Ecological Sciences and Chemical Technology prepared an inventory of thermal effects research programs currently being sponsored by states, federal agencies, private institutions, and electric utilities not included in a previous inventory of research by investor-owned utilities. Literature reviews included a critical analysis of ecological effects of entrainment (i.e., organisms being pumped through the condensers of a power plant) and long discharge canals, and a review of all the thermal effects literature for calendar year 1970.

In the record are several interesting ORNL ecology studies so far. One estimated the thermal resistance (or survival times) of the local Asiatic clam when heated. This clam is a nuisance in condenser cooling systems and may be susceptible to control by back-flushing warmed water through the intake. Such a system has been used successfully against marine fouling organisms and is an alternative less damaging to other organisms than the use of chlorine.

Researchers have looked at the effects of thermal acclimation on feeding competition between rainbow trout and bluegill. As one might expect, the cold-water trout competes progressively worse at high temperatures. One significant outcome was finding the temperature, 72.5°F, at which competition is equal between the two species. Such sublethal effects of temperature are important for continued long-term survival of a species in nature.

In another laboratory study, techniques of gel electrophoresis were used to determine changes in blood protein components following thermal shocks. The Mathematics Division provided the advanced statistical technique of canonical analysis to determine significant changes.

A current study seeks to quantify the role of temperature change on the relative susceptibility of two fish species, largemouth bass and native goldfish, to predation by large bass. Vulnerability to predation may be found to change with temperature much as was feeding competition.

In summary, the first year of intensive ecological research in the thermal effects area at ORNL has resulted in a significant amount of information that can be considered helpful and important to power plant designers. The times move faster than can fundamental research, however, and decisions are in danger of being made every day on the basis of scanty data. The Laboratory, with its blend of capabilities in a range of fields from ecology to reactor engineering, may well be in a position to provide the most important answers with unique speed and efficiency.

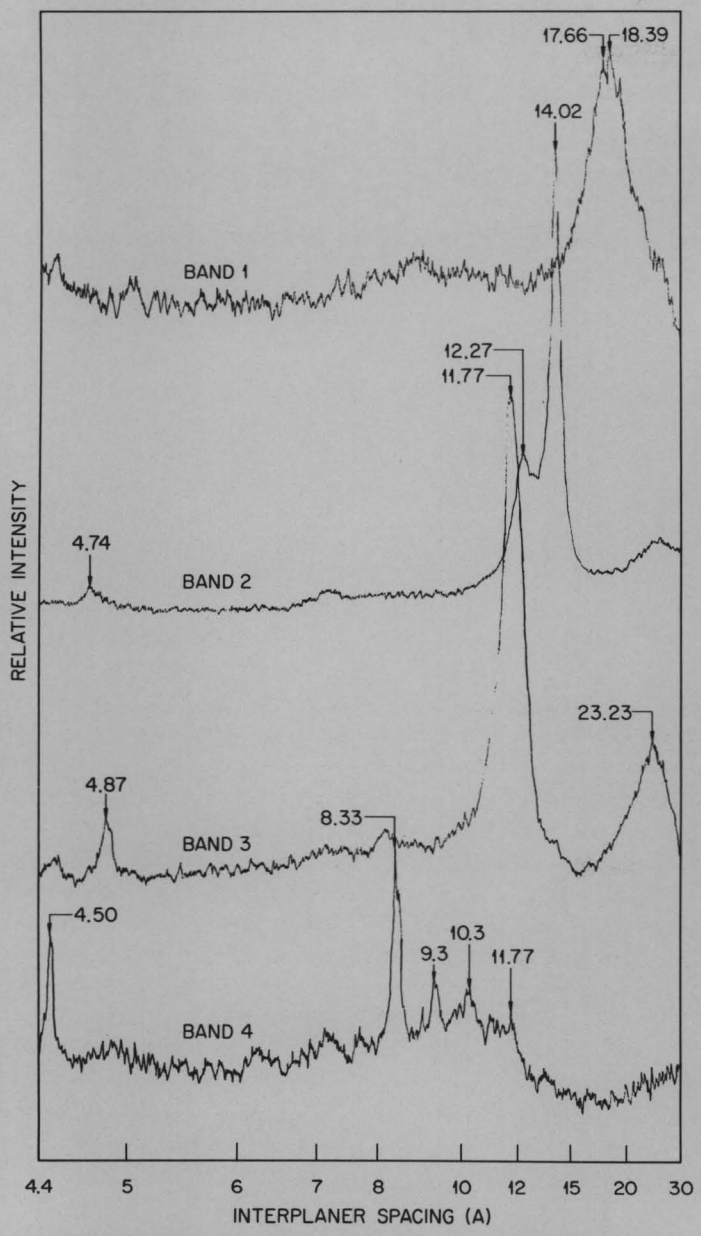
Zonal Centrifuge in Soil Analysis

With pressures to increase food, fiber, and lumber production, it becomes ever more necessary that we use our soil resources wisely. This wise use can only come from understanding the nature and properties of this limited resource. The nuclear industry has already contributed greatly to understanding soils, especially by the wide application of radioisotopes. More recently the development of the zonal centrifuge primarily for biological applications has been adapted by the Health Physics Division for use in soil investigations.

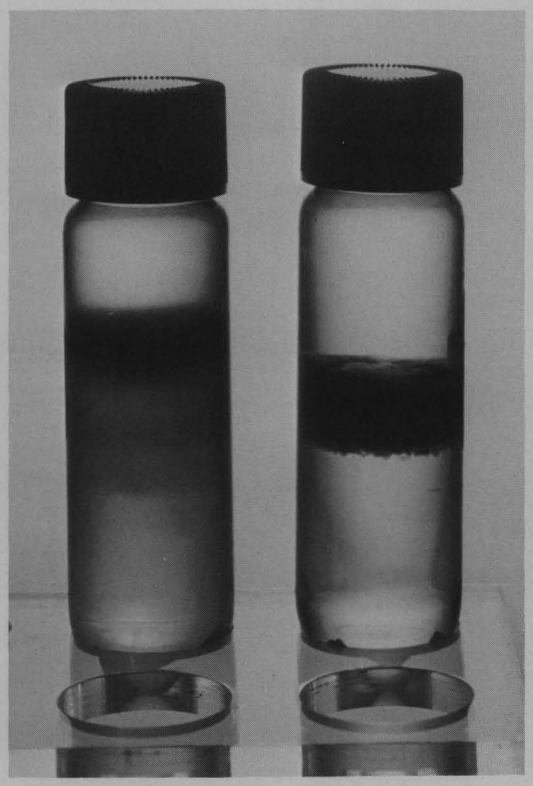
By proper selection of high- and low-density liquids and precise proportioning of these liquids into tubes, a solution is formed with the top portion being as "light" as water and gradually becoming heavier with the bottom being three times heavier than water. To this solution, the soils are added and the tubes centrifuged until the different components of the soil reach a point in the liquid which has the same weight as the material and remains there. In this way the organic and humus material, clay minerals, limestone, and heavy minerals can be isolated from each other. This separation allows the constituents to be identified and their respective properties defined. By comparing soil samples from different locations or different depths, it is then possible not only to locate nutrient elements or pollutants, but more significantly the association of these materials with specific minerals or components of the soil can be noted.

An illustration of the application of this tool is given by our studies of phosphates — a nutrient much in the limelight recently. Classical techniques suggested that in a pond sediment the phosphate was present as calcium phosphate, which has limited availability to plants under the condition existing in the pond. However, after being subjected to zonal centrifugation, the phosphate was shown to be present as aluminum and iron phosphates, which, under the existing pond conditions, are much more available to plants. The "culprit," as it turned out, that led to erroneous identification, was limestone, which had competed with the extracting agent used in the earlier analysis.

In soil studies, it is common to compare test results with reference clay minerals; the latter minerals are considered to be "pure." One of these minerals is illite, important in soils because it contains the nutrient potassium. When illite was subjected to zonal centrifugation, four distinct fractions were recovered. Three of the fractions, when examined by x-ray methods, revealed subtle differ-



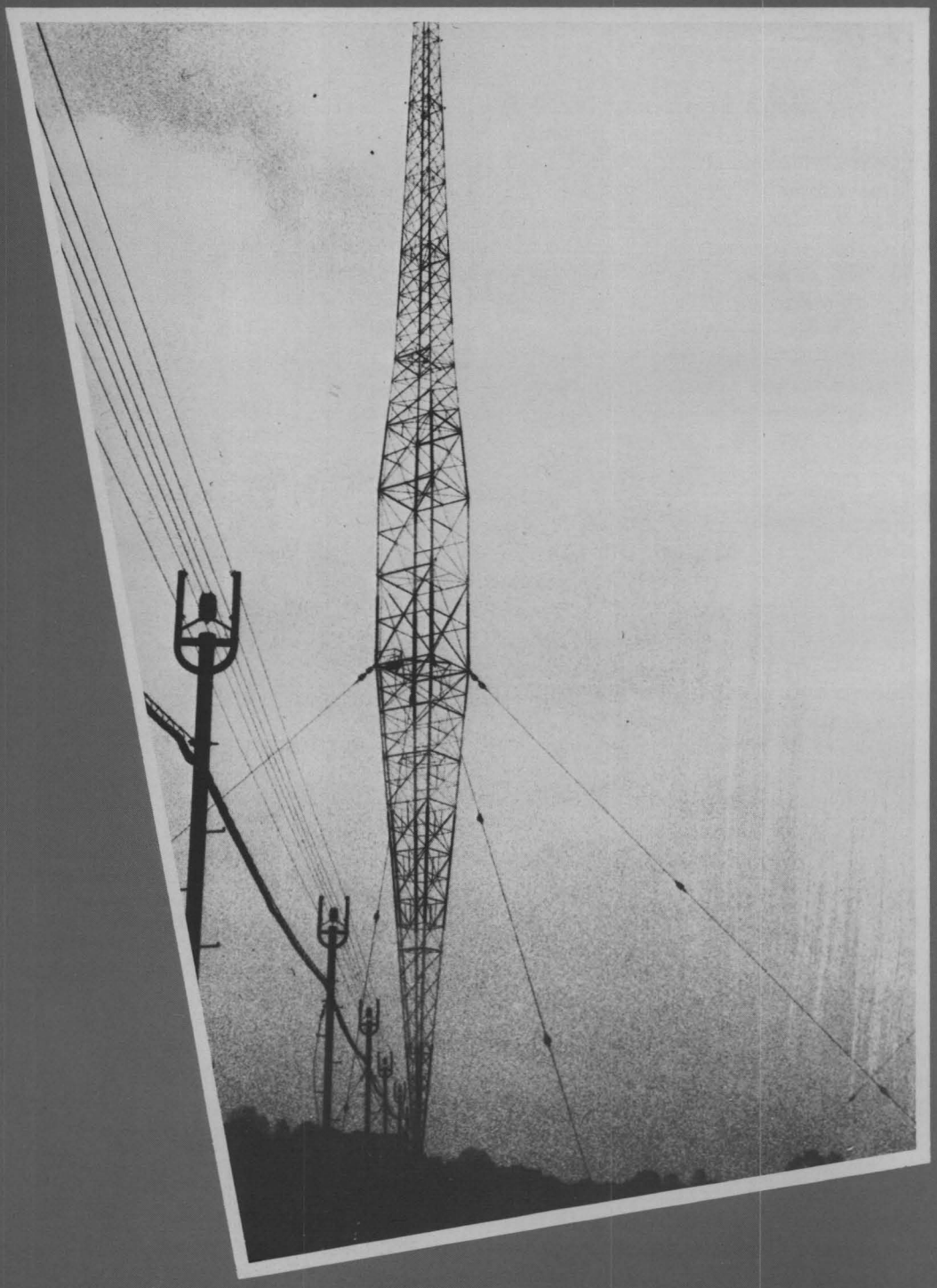
X-ray diffraction tracing of fractions of a "vermiculite" banded by zonal centrifugation. Major minerals include montmorillonite (18 A), vermiculite (14 A), hydrobiotite (12 A), and tremolite (8 A). The banding of the minerals was similar to that depicted in the left tube in the photograph on the right.



One of the problems encountered before zonal centrifugation could be applied to soil systems was flocculation or "curdling" (right tube). By adding a polymer to the system, flocculation was prevented, and the mixture of minerals present in the system was successfully separated (left tube).

ences which could be overlooked if jointly examined. Although at this stage this separation raises questions, systematic characterization should provide a better understanding of the potassium-supplying power of this mineral. Another mineral commonly sold as "vermiculite" was examined by zonal centrifugation. Several mineral fractions were identified in this separation by x-ray diffraction. These mineral studies will make possible better understanding of soils and their properties, and from this lead to more efficient use of fertilizers and pesticides.

CIVIL DEFENSE PROJECT



Nuclear EMP

The nation's Emergency Broadcasting System (EBS) is a voluntary organization designed to maintain communication between government authorities and the public in the event of a nuclear attack. However, radio stations of the EBS may be themselves subject to damage from the electromagnetic pulse produced by the otherwise undamaging high-altitude nuclear detonations of either attacking missiles or our own anti-ballistic missiles, according to findings made in 1970 during a study on the subject in the ORNL Civil Defense Research Project. Such damage could be particularly significant if it occurred before the stations had time to warn the public of nuclear attack.

The destructive electromagnetic pulse that results from the detonation of a nuclear weapon is referred to as nuclear EMP, and it consists of intense, transient electric and magnetic fields that have a devastating effect on some broadcasting stations. It may be compared to a direct stroke of lightning, audible in milder forms as static on AM stations. Such static is itself a radio signal, and the lightning currents form the transmitter and antenna. However, in the case of EMP, the currents are so intense that the signal is much stronger than that from a lightning stroke. Although the pulse lasts only a fraction of a second, its intensity is such that when picked up by radio antennas or any other conductor, such as electrical wires, it can cause damage or malfunction to electrical or electronic equipment.

The EBS, through the many individual AM broadcast stations associated with it, serves at present as the only means of verbally warning the public of nuclear attack. Since even with limited fallout protection, the number of casualties depends on the amount of tactical warning time available, it is essential that the EBS function properly.

Reliable operation of the EBS is also important during and after attack for such functions as providing information on fallout radiation levels, confirming the end of attack or of additional waves of attack, mobilizing civil defense teams, etc. Because AM transistor radios are widely available and generally immune to EMP damage, public communications could be maintained both during and after nuclear attack if the transmitters survived.

The objectives of the study were to analyze the vulnerability of the Emergency Broadcasting System, and particularly the associated AM radio broadcast stations, to the effects of EMP from a thermonuclear attack on the United States and, where damage appeared likely, how to counter it.

Research for the study included visits to AM broadcasting stations in the EBS and interviews with both operating and engineering personnel, discussing equipment and practices relevant to

EMP vulnerability; collecting information on station damage by direct lightning strokes; theoretical analyses, by computer simulation, of surges induced by EMP on broadcast antennas, power lines, and other cables leading into the transmitters; and determining the components most likely to be damaged by EMP.

Research results indicate that the greatest threat from EMP to the EBS is from high-altitude nuclear explosions, which can affect a total area of millions of square miles, that is, a large fraction of the United States. For a high-altitude detonation, nearness to probable target is not a meaningful concept; most stations are threatened by most bursts. Thus, damage to electrical and electronic equipment can occur at distances from the explosion great enough to be completely free from blast or other effects (except possibly fallout). Further, high-altitude bursts are no longer unlikely. They may occur from the Spartan megaton-range warheads of our own Safeguard ABM defense system or from the launch of Soviet FOBS (Fractional Orbit Bombardment System) missiles. If FOB missiles were detonated in orbit at a height of 90 to 180 miles, intense EMP could be produced over most of the United States after, at most, 3 to 4 min of warning time. This is less than the expected activation time for the EBS (about 5 min) and, at best, would allow only 1 or 2 min of warning message broadcast before the first of perhaps several EM pulses were produced.

EMP damage most likely to affect station operation consists primarily of burned-out components (capacitors, rectifiers, transistors, and possibly vacuum tubes), with the transmitting antenna and the power lines serving as the principal conductors of the energy damaging the transmitter.

Experiments are required in order to pinpoint the damage, but the effects of EMP on broadcast stations are in some respects greater than those of the most severe direct lightning strokes to antenna and power lines. Thus, surge arrestors, spark gaps, and other equipment designed to protect against lightning may be inadequate to safeguard the system against the effects of EMP.

There are no procedures or inexpensive hardware currently available to guarantee freedom from damage to a given station. However, because of current uncertainties about both the effects of EMP and the reliability requirement of the EBS, neither additional hardware nor conservative overdesign to achieve very high reliability is recommended at this time.

At the present the best hope that the EBS will function during the most critical time, the tactical warning period, lies in the redundancy in the number of stations. Encouragement, too, lies in

the rugged design of broadcast transmitters, the generally high caliber of the station engineers, and the presence in most stations of a well-stocked supply of parts to replace those most likely to be damaged by EMP. The practice in many stations of maintaining two transmitters with provision for rapid switching between them decreases somewhat the likelihood of disabling damage. However, in a realistic attack many pulses would be expected within a short time. If the first transmitter were damaged and the second switched on before the last detonation, it too could be disabled.

Certain recommendations resulted from the study. First, station engineers should be told that EMP exists and that it can damage their transmitting equipment in much the same way as lightning — the transmitting antenna and the power line being the most likely sources of damaging energy.

Second, attack warning signals should be sent to EBS stations on a priority basis so that they could switch immediately to generator power, isolating themselves from the power line as completely as possible.

Third, radiation detectors should be provided to all EBS stations, since personnel would have to leave fallout shelters to make many repairs.

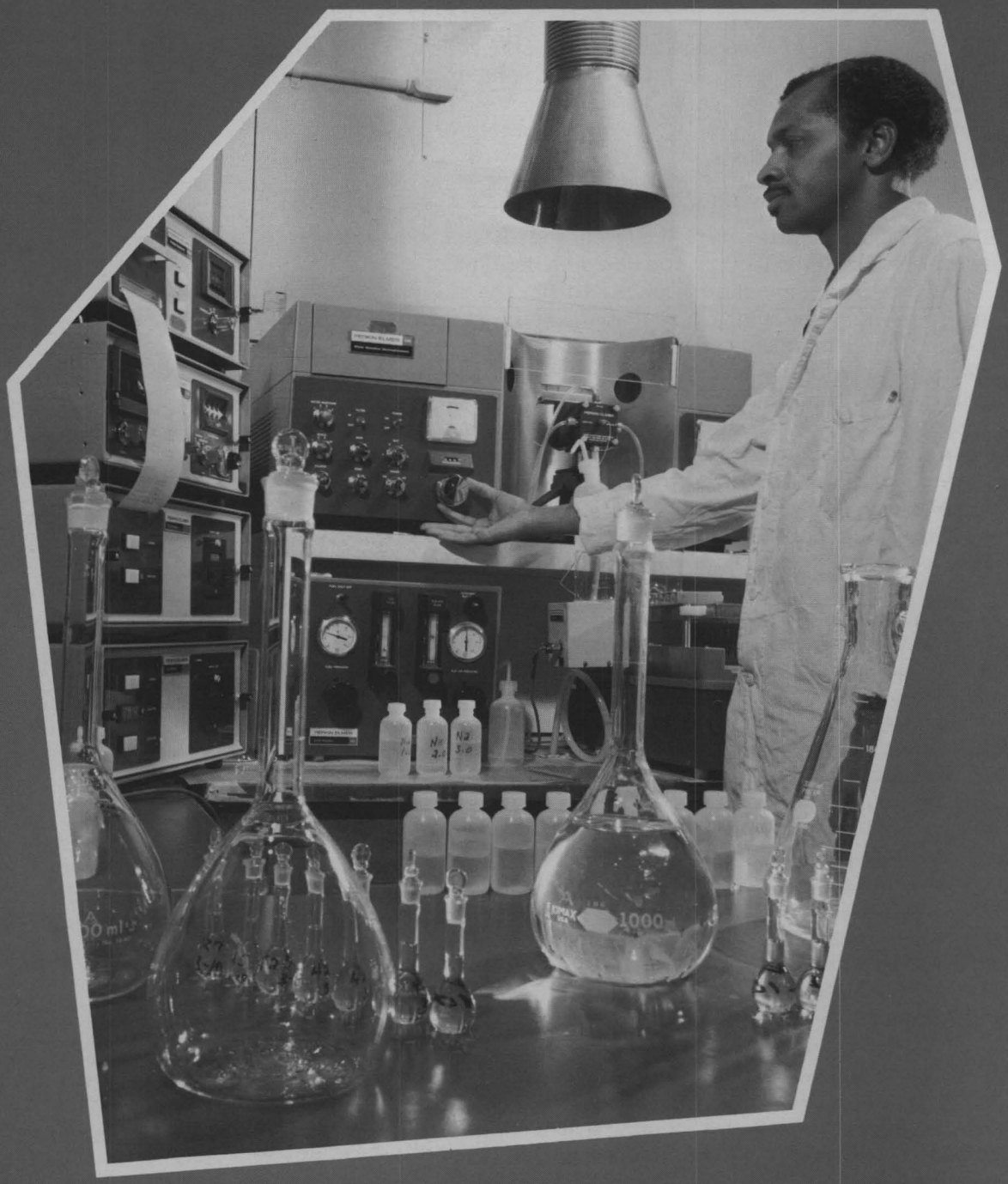
Fourth, stations should maintain stocks of spare parts, particularly capacitors and possibly antenna coaxial cable feed lines. Since this is already customary, the recommendation would ensure that stocks were not permitted to get low.

Fifth, a microphone and basic audio console should be kept at the transmitter site of stations.

The number and diversity of EBS radio stations make the addition of high-confidence EMP protection technically and economically unattractive. A better hope for significant improvement appears to be the proposed DIDS (Decision Information Distribution System). This warning system features ten very low frequency transmitters across the country to broadcast the warning message directly to receiving terminals and possibly to the general public. Funds have been appropriated for the first of these, to be located in Maryland. EMP protection is to be incorporated from the beginning in all transmitters and receivers.

This system has two advantages over the EBS with regard to EMP. First, the small number of transmitters makes EMP protection fairly easy at sufficiently low cost, a possibility that does not exist for the EBS. Second, the speed of activation (half a minute as compared with 5 min for EBS) increases the possibility of adequate warning before the first EMP is generated.

AFFIRMATIVE ACTION PLAN



The Affirmative Action Policy

It is the policy of the Corporation to afford to all people under normal retirement age without regard to race, color, religion, sex, or national origin, except where sex is a bona fide occupational qualification, equal opportunity in employment, for advancement in employment, and for continuation of employment with due regard for the relative qualification of all involved.

Achieving a true state of equal employment opportunity at ORNL is seen by its management to rank in importance with the solving of its most significant technical problems. In order to realize this goal, the Laboratory has developed an Affirmative Action Plan which clearly delineates policy, points to deficiencies that should be corrected, and sets positive goals to be reached at determined future periods.

ORNL is pledged to attain the condition of equal opportunity, and Affirmative Action is the plan by which it will be achieved.

During the past three years, in spite of the decrease in employment levels and hiring opportunities at ORNL, total minority employment increased from 5.1% to 5.7% in permanent staff. It is with gratification that the Laboratory can state that in 1970 nearly 20% of all hires were minority, and of these, 76% were in occupational categories above the unskilled and service worker levels. In the office and clerical occupations, 30% of all hires were minority. Further, and of greater importance, there was a steady upgrading of minority employees into the more advanced occupations, as well as a wider dispersal of these employees throughout the Laboratory.

Although it will be difficult to make significant gains in the near future because of the financial picture, the Laboratory will continue in its policy to take every opportunity to hire and upgrade qualified members of minority groups. On-the-job training where practical will be continued, and, consistent with the Laboratory's mission in education, so will participation in a number of training programs with predominantly black colleges and universities.

ORNL is committed to comply in fact, as well as in spirit, with the public policy on equal employment opportunity. Its goal is to establish a record that can be viewed as a model for similar organizations.

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Mid-Southeast Chapter, Association for Computing Machinery Chairman: C. S. Williams, ORNL	March 20
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Conference on Beneficial Uses of Waste Heat Chairman: J. H. Gibbons, ORNL	April 20–21
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Southeastern Industrial Health Conference Chairman: N. E. Bolton, ORNL	September 30–October 2
Conference on Analytical Chemistry in Nuclear Technology Chairman: L. J. Brady, ORNL	October 12–15
Continuum Aspects of Graphite Design Chairman: B. L. Greenstreet, ORNL	November 9–11

MAJOR CONFERENCES SPONSORED OR COSPONSORED BY ORNL IN 1971

Industrial Cooperation Conference on Automated Pipe Welding Chairmen: G. M. Slaughter and P. P. Holz, ORNL	February 25
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Symposium on Training of Nuclear Facility Personnel Chairman: J. A. Cox, ORNL	April 19–21
Press Seminar: Technology for a Better Environment Chairman: D. A. Sundberg, ORNL	April 25–28
Studies in Applied Solid Mechanics Chairman: B. L. Greenstreet, ORNL	April 26–28
AESOP-4 Conference Chairman: L. C. Toomer, ORGDP	May 4–6
National Symposium on Radioecology Chairman: D. J. Nelson, ORNL	May 10–12
Fetal Antigen Conference and Workshop Chairman: N. G. Anderson, ORNL	May 24–26
International Fusion Reactor Technology Conference Chairman: D. Steiner, ORNL	June 28–July 1
International Symposium on Research Materials for Nuclear Measurements Chairman: E. H. Kobisk, ORNL	October 4–8
Association for Computing Machinery Conference Chairman: C. Price, CTC	October 8
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Workshop on Statistical Interpretation of Mammalian Survival Experiments Chairman: H. E. Walburg, ORNL	October 20–23
Multiply Charged Heavy Ion Sources and Accelerating Systems Chairman: R. S. Livingston, ORNL	October 25–28
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